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Module I: Innovative feeds and feeding strategies for improving welfare & performance of fish in sustainable and organic aquaculture

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FutureEUAqua project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 817737

Module Description

- This module will demonstrate sustainable and resilient nutritional solutions aimed at the highest possible fish performance in the framework of a safe and sustainable aquaculture.
- It will cover innovative, species-specific nutritionally adequate, tailor-made, low ecological footprint fish diets and their nutritional impact on farmed fish growth performance, health and quality for a better performing sustainable and organic aquaculture.
- In addition, the module will highlight how the understanding of the impacts of environmental change and human activity on farmed fish can be greatly enhanced by the use of Internet of Things.
- Indeed, the knowledge of life traits, such as fish behavior, condition, physiology and the farming environment will be significantly improved by using electronic sensors, providing industry with information needed to facilitate health/welfare and optimal management practices.
- The module builds on the basic knowledge of fish biology, physiology and biochemistry.

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Module Description

The module is organized in four sessions:

- Session I - **Fish nutrition in aquaculture**
- Session II - **Internet of Things for healthy fish and environment**
- Session III - **Innovative fish feeds for health fish for a healthy human consumption**
- Session IV - **Metabolic traits of free-swimming fish in aquaculture**

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Learning objectives

At the completion of this module participants will be able:

1.

To be acquainted with understand the role of nutritional research in sustainable and organic aquaculture

2.

To explain how Internet of Things (IoT) can contribute to precision livestock farming, by enhancing animal welfare, but also production and environmental sustainability

3.

To comprehend the relationship between innovative fish feeds and nutrition for the production of a healthy fish

4.

To understand how the measurements of fish metabolic rates have been proven to be sensitive for monitoring welfare & performance in farmed fish

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Module Outlines

1	**Introduction/background**	Knowledge gaps; Key concept
2	**Session I**	**Fish nutrition in aquaculture;** Basic issues in fish nutrition; Essential nutrients, micro-macronutrients and nutrient energy; Fish species-life stages-specific nutritional requirements; Digestion, absorption, metabolism and biochemical function; Fish growth and physiological functions.
3	**Session II**	**Internet of Things for healthy fish and environment:** State of the art of sensors technologies; Precision livestock farming; Fish tracking; Environmental monitoring; Data modelling.
4	**Session III**	**Innovative fish feeds for health fish for a healthy human consumption:** Feed ingredients, raw material quality, diet formulation, feed manufacturing and technology, feed efficiency, feeding management, novel sustainable fish feeds.
5	**Session IV**	**Metabolic traits of free-swimming fish in aquaculture:** Measure of swimming performances (Ucrit); Estimation of metabolic rates; red and white muscles activation pattern; Calibration of MO_2 with the acceleration.
6	**Glossary**	
7	**References**	

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Knowledge gaps

- The fish farming industry needs instruments that can monitor in real time fish health and welfare objectively, without killing or disturbing the fish or interfering with the daily management.
- Modelling key performance indicators to forecast growth performance and mortality by using physiological and environment parameters would be a further step forward.
- Feeding the future farmed fish by formulating sustainable/ecological feeds and providing the dietary essential nutrients to meet the species-life stage-specific nutritional requirements to promote optimal growth and health.
- Understanding the dietary supply line of essential nutrients in relation to their bioavailability to obtain the best feeding strategy for farmed fish

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Key concepts

- The contribution of precision livestock farming to enhance animal welfare, but also production and environmental sustainability.
- The knowledge of fish metabolic rates to improve welfare & performance in farmed fish.
- Critical thinking in nutrition and the knowledge of fish nutrition
- The evaluation of the formulation of ecological, tailored-made species-life stage-specific fish diets

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SESSION I: Fish nutrition in aquaculture

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As a general principle in nutrition of farmed aquatic animals

Feeds should meet all **nutritional requirements** of the organisms, **promote** animal's **well-being, health and growth**, ensure **high quality** of the final product and have **low environmental impact**.

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Nutrition

Nutrition:

- the provision of all indispensable nutrients in adequate amounts to insure proper growth and maintenance of body functions
- involves various chemical reactions and physiological transformations which convert feed into body tissues and activities
- involves ingestion, digestion and absorption of various nutrients
- transport into cells
- removal of unusable elements and waste products of metabolism

Nutrient: nutrients are chemical compounds in feed that are used by the animal organism to meet its physiological function, grow and maintain health

Essential nutrient: provided in the diet in order to insure adequate growth and maintenance.

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Nutrition

Nutrient categories: macro and micro

-**macronutrients**: protein, lipid, carbohydrate, etc.

-**micronutrients**: trace metals, vitamins, amino acids, fatty acids

Nutrient requirement: The amount of each specific nutrient that fish needs to sustain all its physiological functions for growth, reproduction while maintain a healthy life.

proteins: g/kg vitamins: µg/kg

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Fish nutrition

For feed producers?

The formulation of tailored made species-specific, low cost, environmentally friendly diets

For farmers?

The optimization of feeding to promote the best fish growth

For the researches/students?

The evaluation of the long-term effects of novel diets to meet fish nutritional requirements and physiological functions and obtain the best fish growth/health performance

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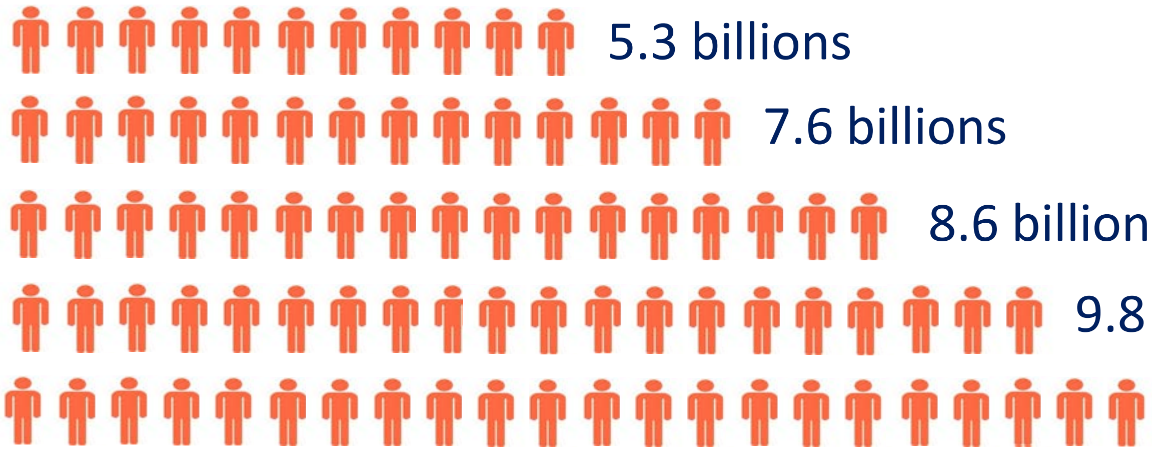
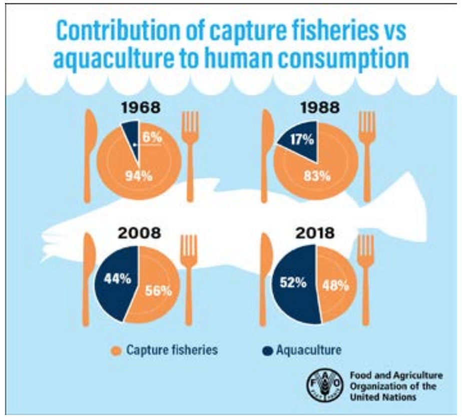
Fish nutrition

Human population is continuously growing

1990 5.3 billions
2017 7.6 billions
2030 8.6 billions
2050 9.8 billions
2100



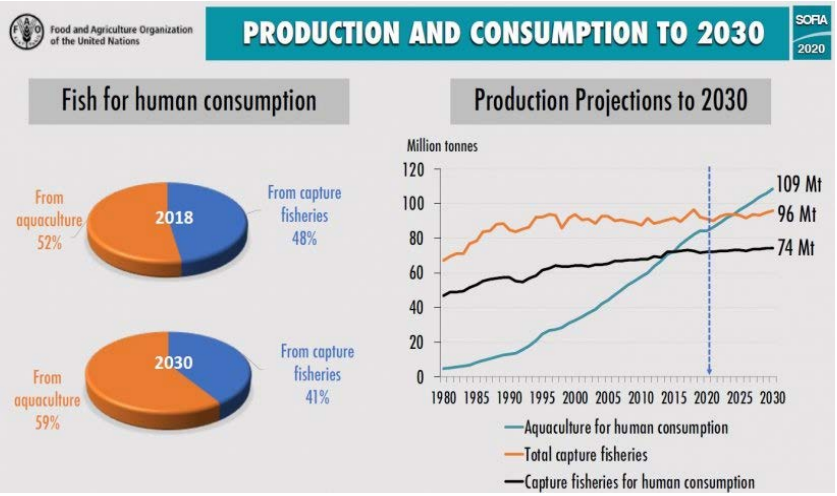
Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2007)



Food-Feeds
Sourcing essential nutrients

AQUACULTURE IS THE FUTURE OF FOOD

By 2030, nearly two-thirds of all seafood produced for human consumption will come from aquaculture [World Bank].



40Mt aquafeeds

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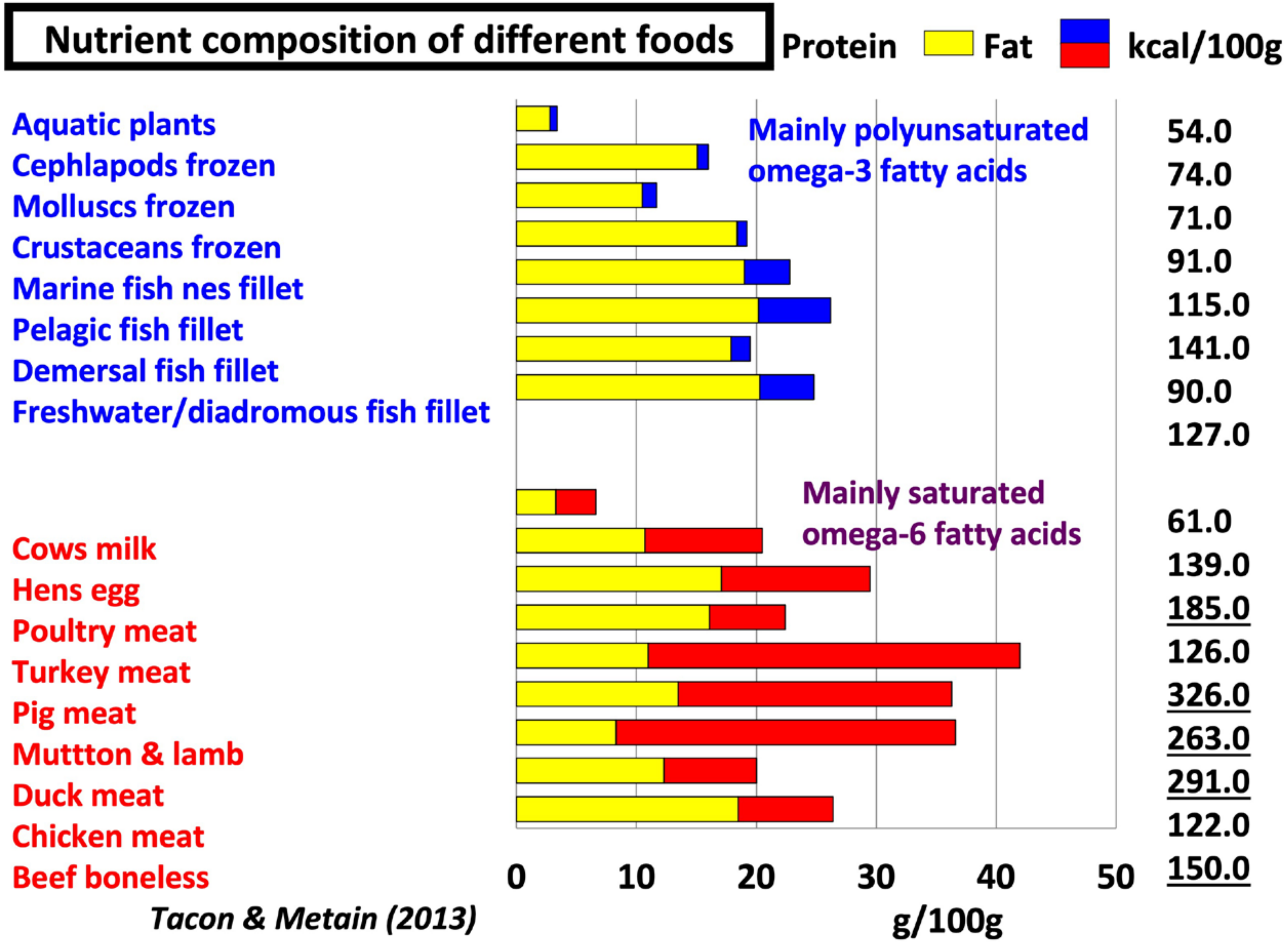
We are what the fish eats



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Fish nutrient requirements

The amount of each specific nutrient that fish needs to sustain all its physiological functions for growth, reproduction while maintain a healthy life.

- The requirement of one nutrient often depends on the quantity and interaction of another nutrient (i.e. optimal histidine/lysine ratio)
- The nutrient requirements depend on: fish age/body mass, temperature, rearing system, fish species- freshwater/marine, coldwater/warmwater
- The nutrient requirements estimates are independent on the amount of the other nutrient if the levels of that nutrient is not limiting (i.e. minimise the impact of nutrient interactions and ensure that they are not limiting, nutrient-based models)
- Values in nutrient requirement tables don't allow for processing or storage losses

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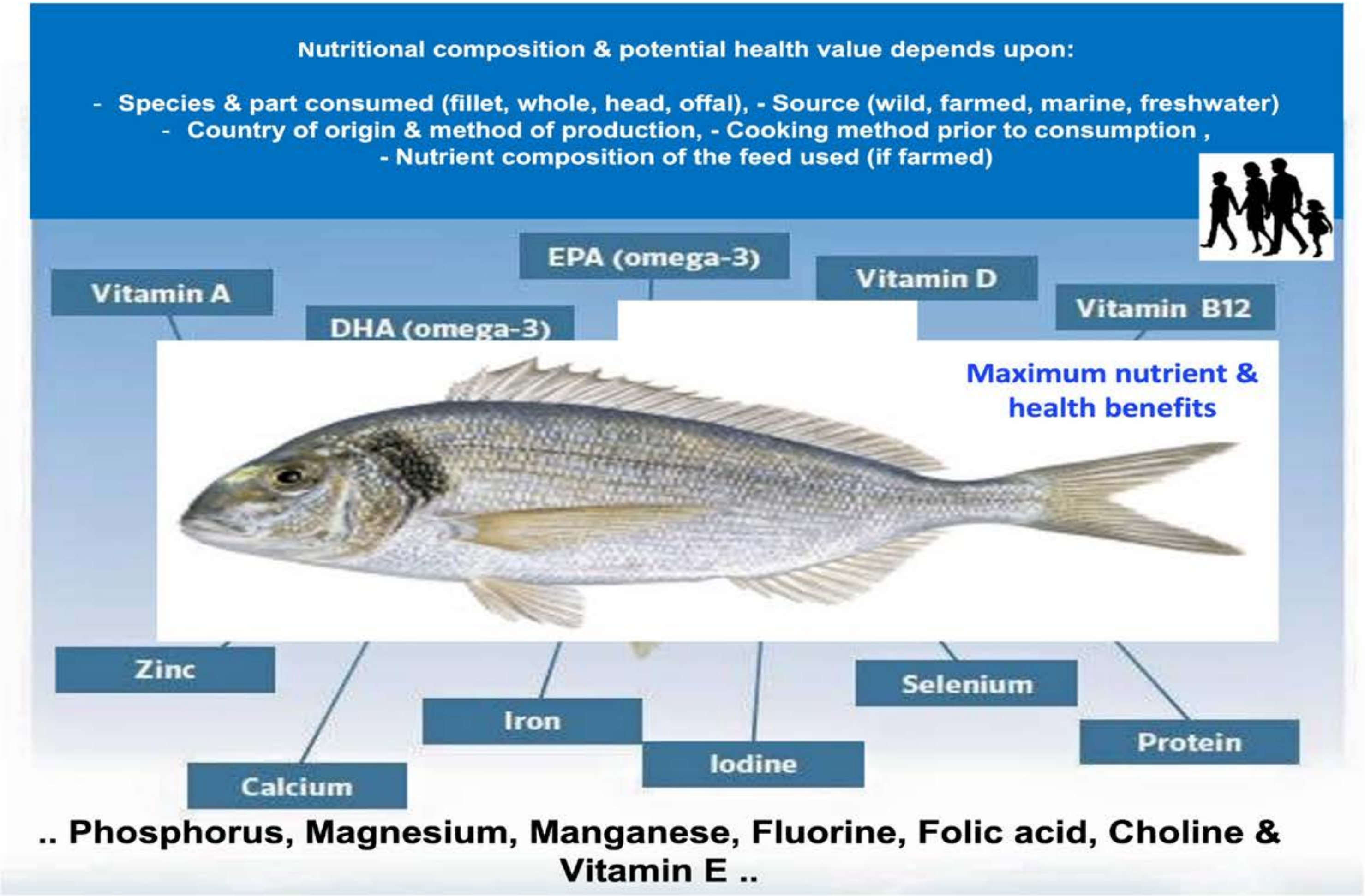
Fish nutritional value



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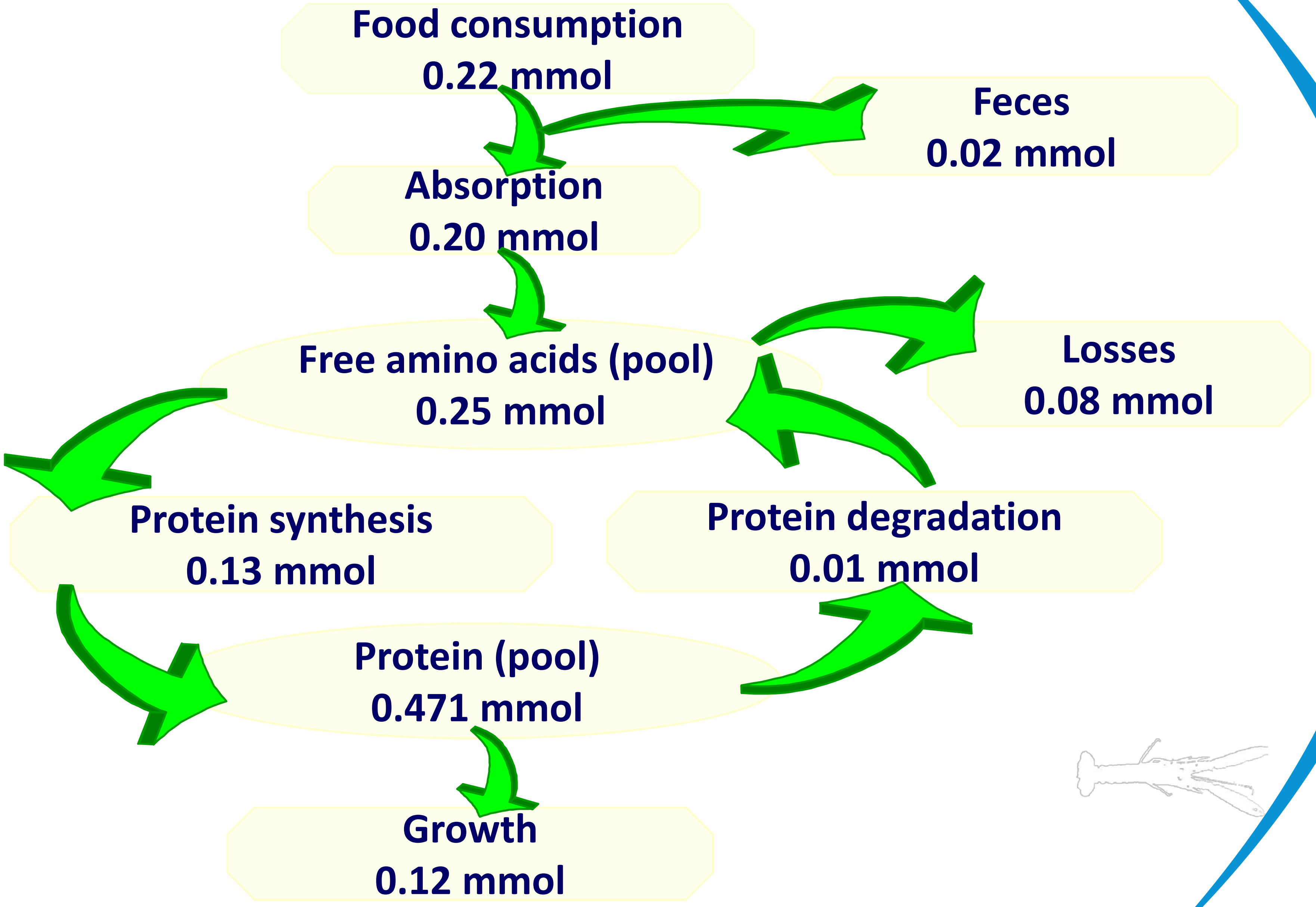
Amino acid flux model



Mente, E., Houlihan, D.F. Coutteau, P. and Sorgeloos, P. (2002). Protein turnover, amino acid profile and amino acid flux in juvenile shrimp *Litopenaeus vannamei*: effects of dietary protein source. *Journal of Experimental Biology*, **205:** 3107-3122.

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Fish digestive physiology

trout
carnivore

catfish

omnivore

carp

omnivore

milkfish

planktivore

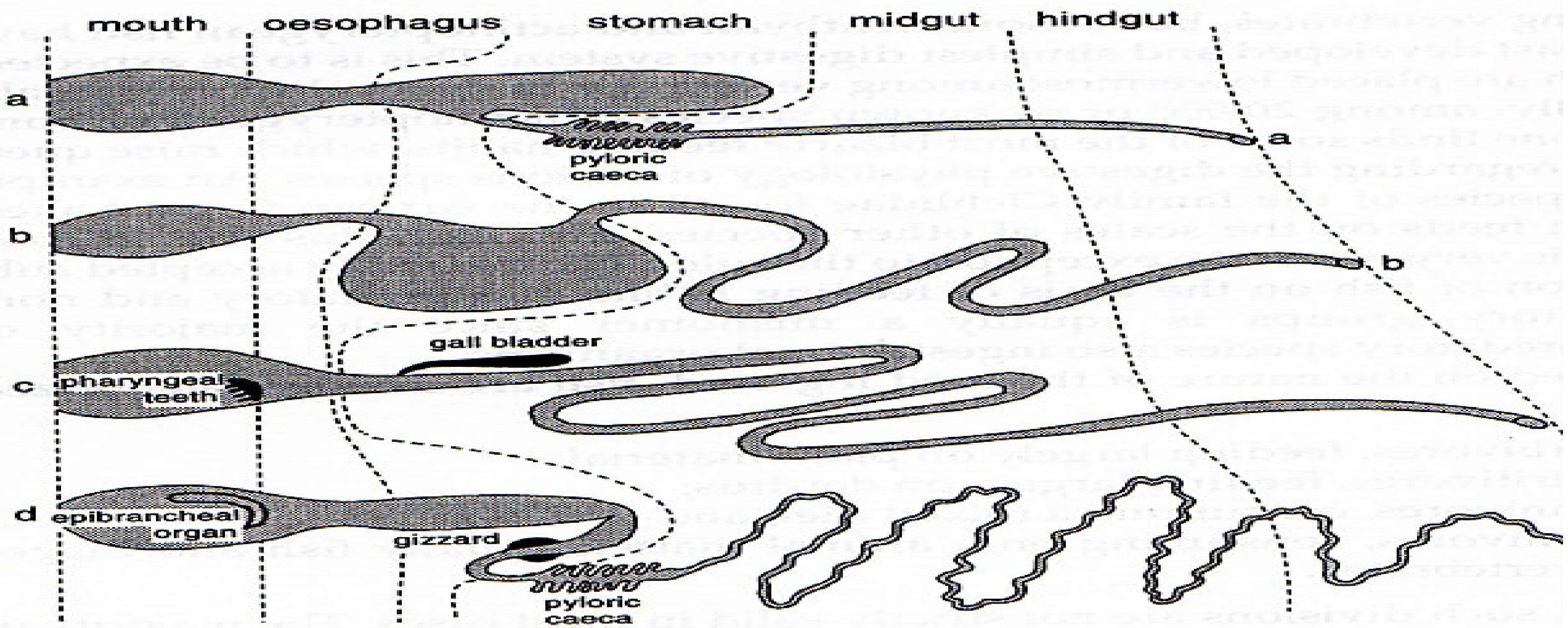

Figure 4.1 The digestive systems of four fish described in the text, arrang order of increasing gut length. (a) Rainbow trout (carnivore). (b) Catfish (omnivore emphasizing animal sources of food). (c) Carp (omnivore, emphasizing plant sources of food). (d) Milkfish (microphagous planktivo (From Smith, 1980.)

De Silva and Anderson, 1995)

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Energy metabolism of farmed fish

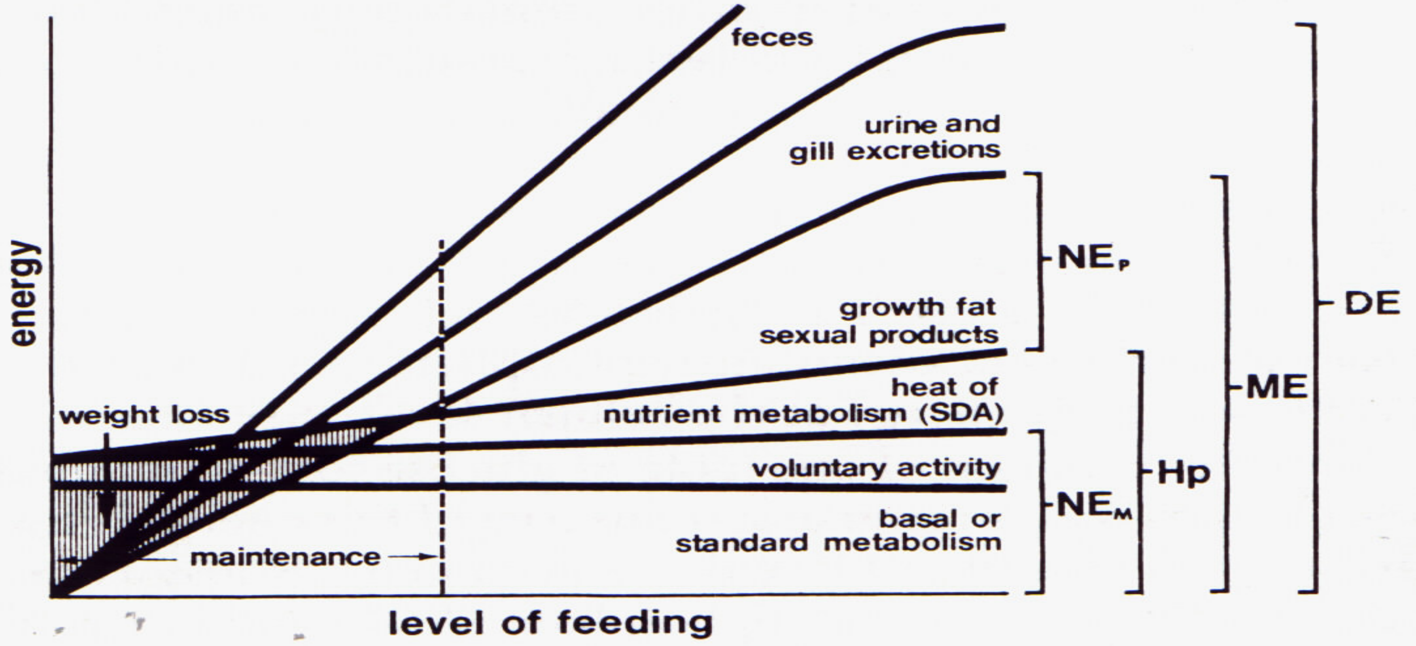

FIG. 1.2

Energy intake and distribution among energy-requiring processes. (From Smith, *In* "Studies on the Energy Metabolism of Cultured Fishes", 1976 Thesis, Cornell University.)

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Fish digestive physiology

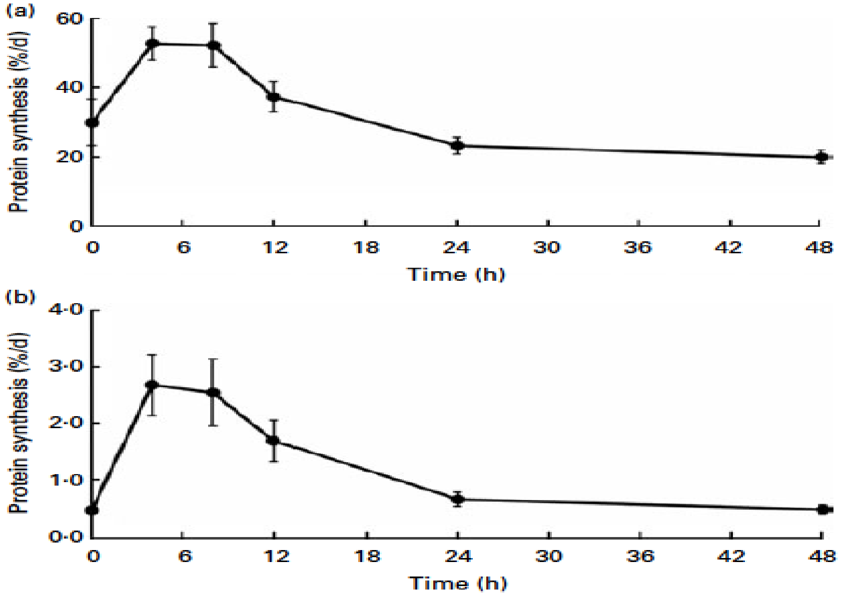
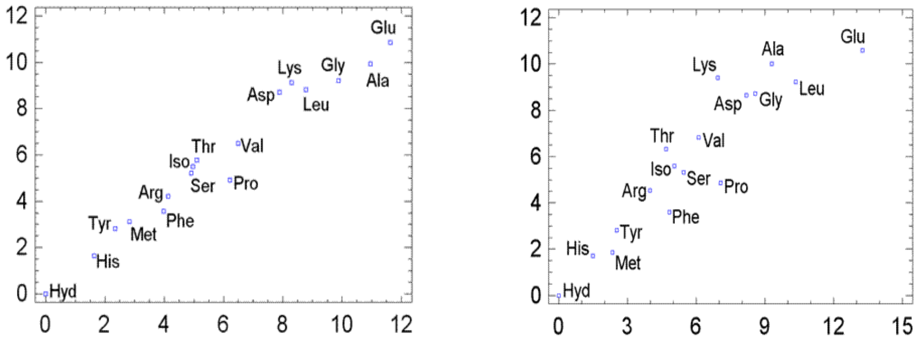


Fig. 2. Protein synthesis (%/d) in (a) liver and (b) white muscle of sea bream before feeding and at different times after feeding. Values are means, with their standard errors represented by vertical bars (*n* 8).

The fish liver has a high capacity to compensate for some nutritional imbalances in order to optimize white muscle protein turnover and prioritise protein growth.



Challenge: Differences in amino acid up-take pattern between fishmeal (FM) and plant meal (PM) based diets

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Fish energy budget

I = M + G + E

where: I = ingested energy

M = energy expended for metabolism

G = energy stored as growth

E = energy lost to environment

- Standard Metabolic Rate
  - maintenance; no growth, no activity
- Routine Metabolic Rate
  - routine growth & activity
- Active Metabolic Rate
  - max. aerobic metabolism

-Feed quantity-quality

-Feed conversion and economic conversion

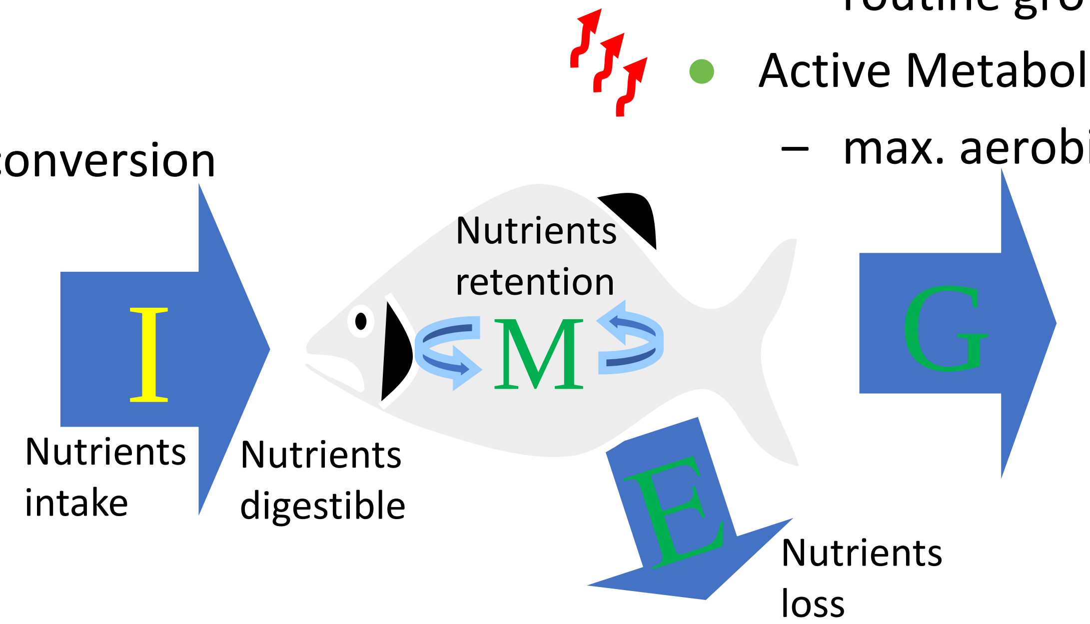
-Feeding costs

-Temperature

-Waste solids N, P

-Oxygen consumption

-NH_3 and CO_2 production



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SESSION II: Internet of Things for healthy fish and environment

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Internet of Things (IoT) is the network of physical objects or «things» embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data.

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- Understanding the impacts of environmental change and human activity on farmed fish can be greatly enhanced by using electronic sensors. Indeed, many questions can only be answered through this approach. Electronic sensors are significantly improving our understanding of fish behaviour and are emerging as key sources of information for improving aquaculture management practices.
- Enhanced environmental (e.g. oxygen, temperature, salinity, pressure) and biological (e.g. behavior, activity, energetic, feeding physiology) sensor data, collected by a network of wireless electronic sensors, can provide accurate fine-scale real-time measurements of environmental conditions, fish health, welfare and habitat use, average fish size and biomass, thus facilitating predictive modelling of the rearing performances and impacts.

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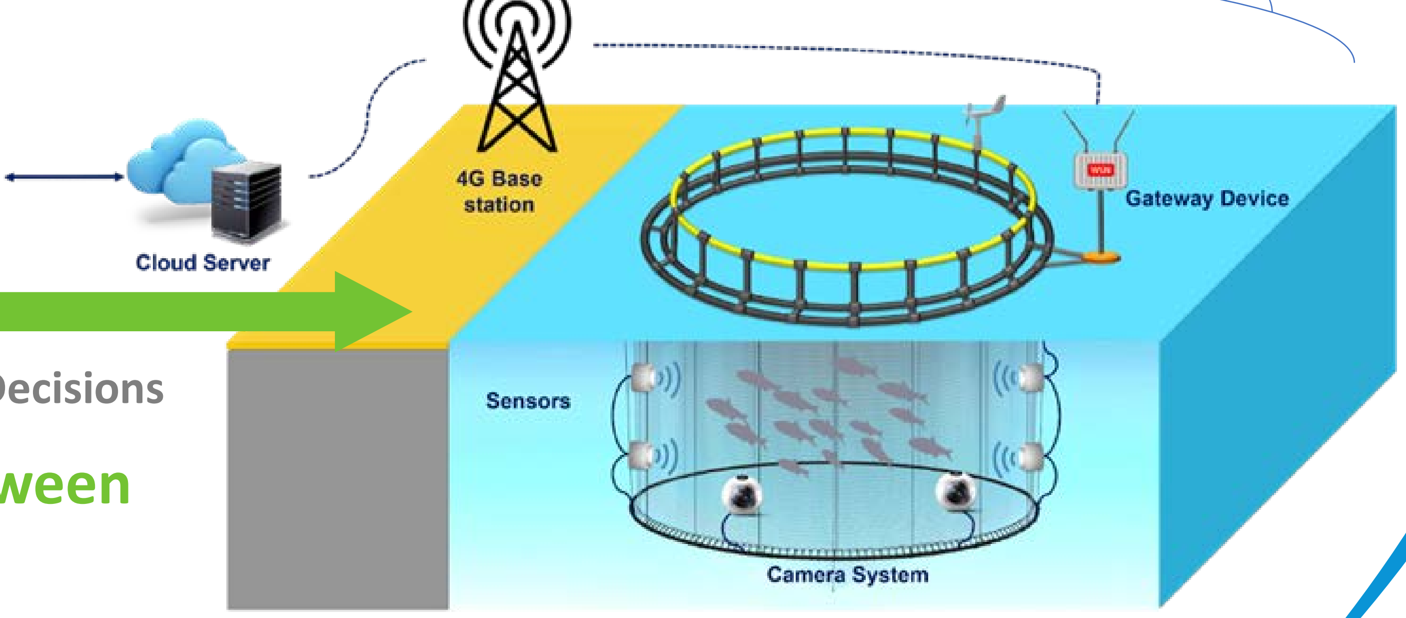
Here you can see a 5 min video on the use of physiological and environmental sensors applied to the aquaculture sector

https://youtu.be/tZGZ9bRmwJ8

Biomass
Water quality
Swimming acitivity
Physiological markers



Feedback / Decisions

Real-time interaction between farm and farmers

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Fish tracking

- In their most basic form, electronic sensors and tags may include radio or acoustic beacons that transmit signals, which can bring specific codes to identify animals, and allow them to be tracked using receivers that detect the transmitted signals (Lennox et al. 2017). Basic archival tags must be, instead, physically recovered in order to obtain the data.
- Because the strength of radio signals, regardless of the longest wavelengths, rapidly attenuate in seawater, acoustic transmissions is preferred for fish tracking in marine environment (Lembo et al. 2002), while radio transmission is commonly used in freshwater environment. More advanced tags incorporate sensors that measure and record a suite of environmental and/or biological parameters of fish (Cooke et al. 2016).

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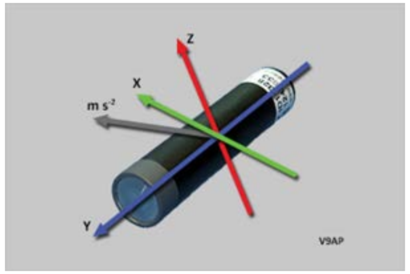

Fish tracking

- Accelerometer pressure tags transmit 3D acceleration of fish as they move within the receiver array, and also transmit depth data. The fish acceleration signal is measured in terms of m/s^{-2} and it is a vector quantity that is a result of measuring acceleration on 3 axes (X,Y,Z). This acceleration value can be used as a measure of activity of a free ranging animal in nature or captivity. Accelerometer tags can be used in a number of applications that require any measure of animal activity. Applications may include measuring swimming speed via tail beat acceleration, detecting mortality through predation, seismic blasting, toxic spills, feeding events, spawning activity, nocturnal/diurnal activity, wave action and activity responses to changing oxygen, salinity and temperature in the environment.

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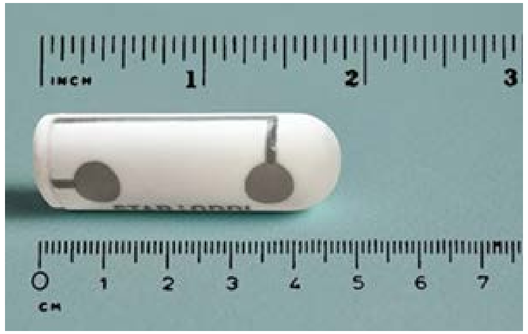

Fish tracking

- Heart tag simultaneously monitors heart rate and temperature in the fish. The data logger has no external wires, which makes it especially simple to implant. It is made of unique ceramic housing and epoxy and is hermetically sealed, guaranteeing biocompatibility. The logger is ideal for monitoring behaviour and stress response of the fish. The heart rate is derived from a leadless single channel ECG. The logger takes a burst measurement of ECG at the set time interval and calculates the mean heart rate for each recording. For validation purposes, individual ECG bursts can be saved.

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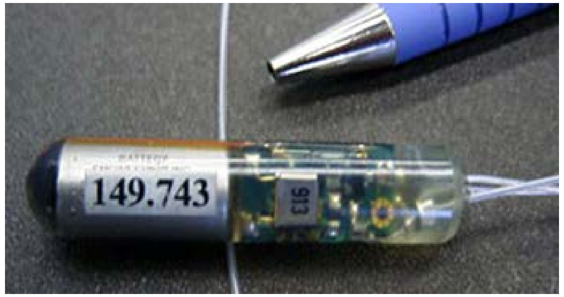

Fish tracking

- Electromyogram tag measures muscle activity using probes inserted into the musculature of the fish. The tag provides a powerful quantitative estimate of the energetic costs associated with physical activity. High impedance EMG signals are processed through an integrator, digitized and then a coded radio sequence is transmitted representing unique identity and data. Electromyograms (EMGs) are records of bioelectric potentials that are strongly correlated with the strength and duration of muscle contractions. Indeed, EMG values averaged over time can be used directly as quantitative indicators of the intensity of fish activity.

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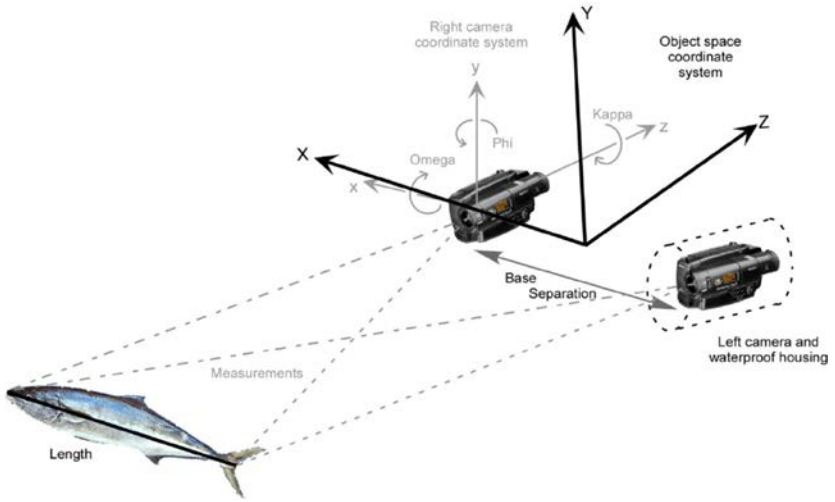
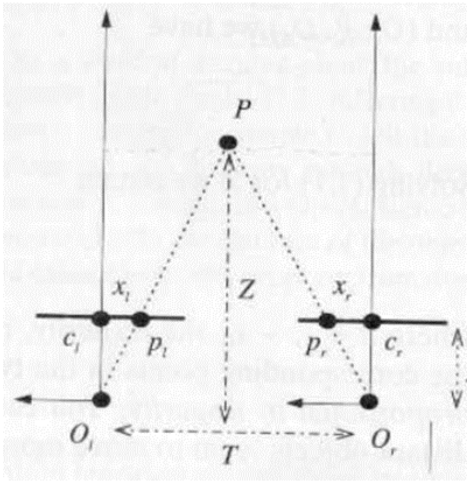
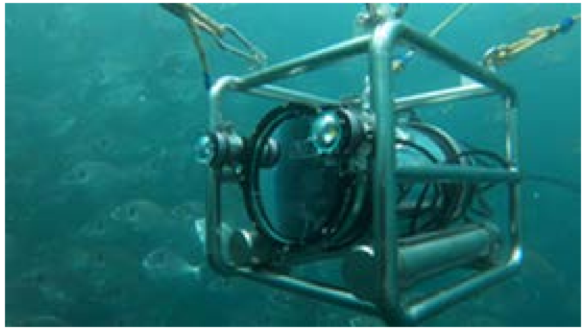
Camera-based biomass estimation systems

Stereo image analysis requires two images of an object from different viewing angles and matching a point in one of the images to a corresponding one in the other. The 2D coordinates of that point can then be used to estimate its 3D coordinates.

Making 3D measurements comes down to accurately identifying and matching pairs of points between the two 2D images.







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Biomass estimation systems: challenges

- Lighting Conditions
- Specialized Underwater Case must be considered for such systems
- Water Turbidity / Salinity affects the accuracy of the system
- Fish Movement / Mobility / Orientation
- Fish specie-specific (due to different morphology)
- Power Consumption Requirements
  - Camera system continuously captures video
  - The Embedded PC constantly process data to detect the required patterns
  - Even when harvesting systems (e.g. large solar panel) are employed the system cannot operate 24/7, due to the high current expenditure
- Big Data Analysis
  - Such systems acquire a big volume of data, thus sophisticated policies must be followed to successfully handle the data
  - Distributed Computing among different devices

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Environmental monitoring

- Wireless sensor networks provide end-to-end solution for farm environmental monitoring, including a cloud platform, a hub and innovative sensors that communicate wireless underwater. These technologies enable data-driven aquaculture farming where knowledge drives better decisions.
- The available sensor options may include oxygen, salinity, pH, temperature, turbidity, chlorophyll, blue green algae and other.

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Environmental monitoring

- A cloud-based platform allows to view and analyse data from the aquaculture sites in real time. The software provides a set of continuously evolving analytics tools that allow to view data. Notifications and alerts allow to receive crucial updates in real time.
- The hub is the core of the system, which keeps data secure, safe and available. Utilizing a digital receiver and a communications modem can support many sensors within a large radius.
- The hub can support many telemetry protocols for cloud communications, including Cellular, Wi-Fi and Iridium.

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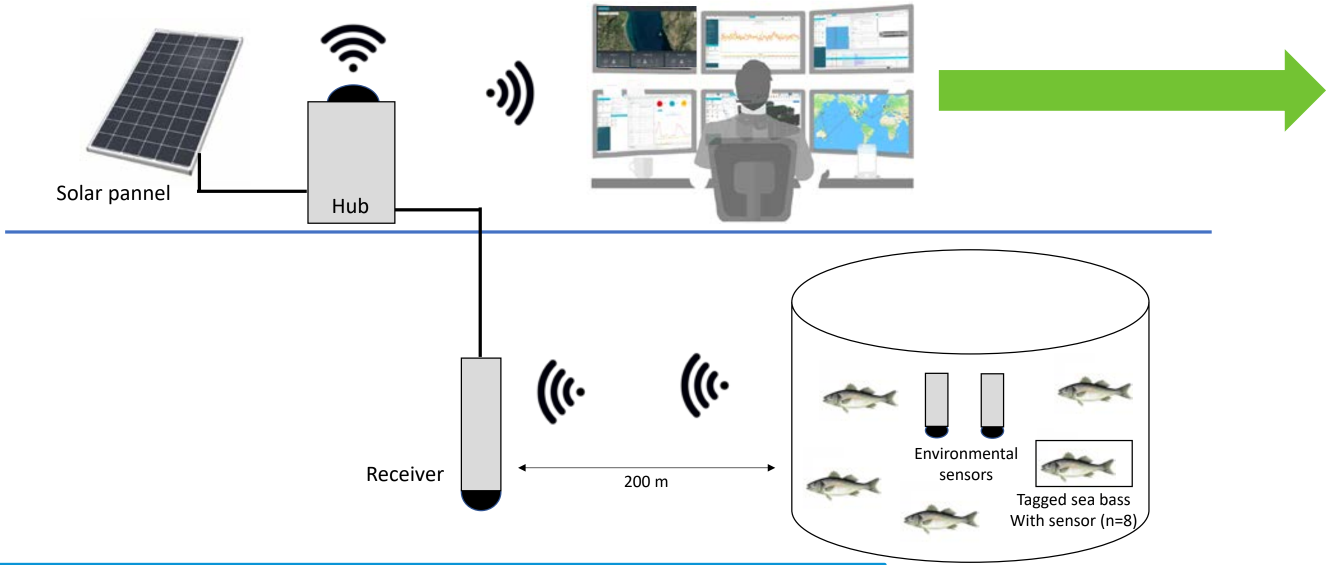
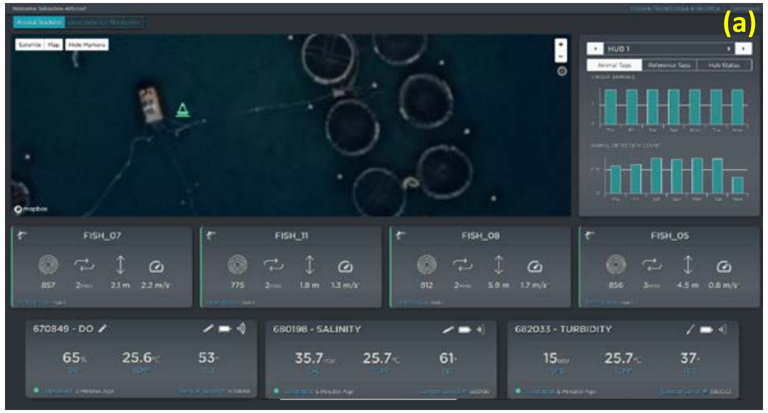
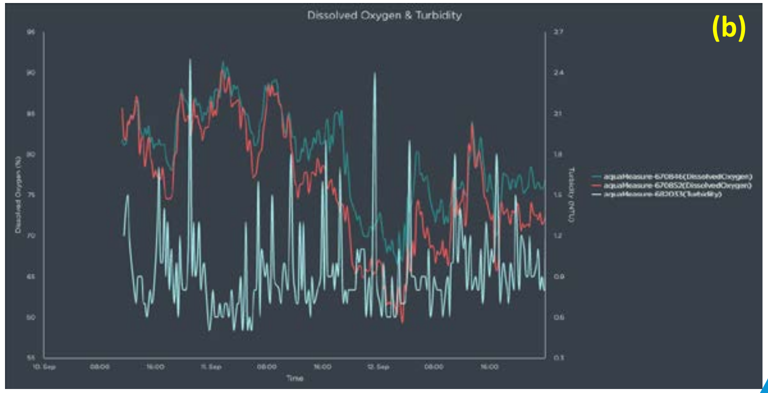
Environmental monitoring & fish tracking



Live dashboard





- **Material:**
- DO sensors (n = 3)
- Turbidity sensors (n = 1)
- Salinity sensors (n = 1)
- Fish tagged with accelerometer tags (n = 8)

The whole system was tested at Kefalonia aquaculture farm

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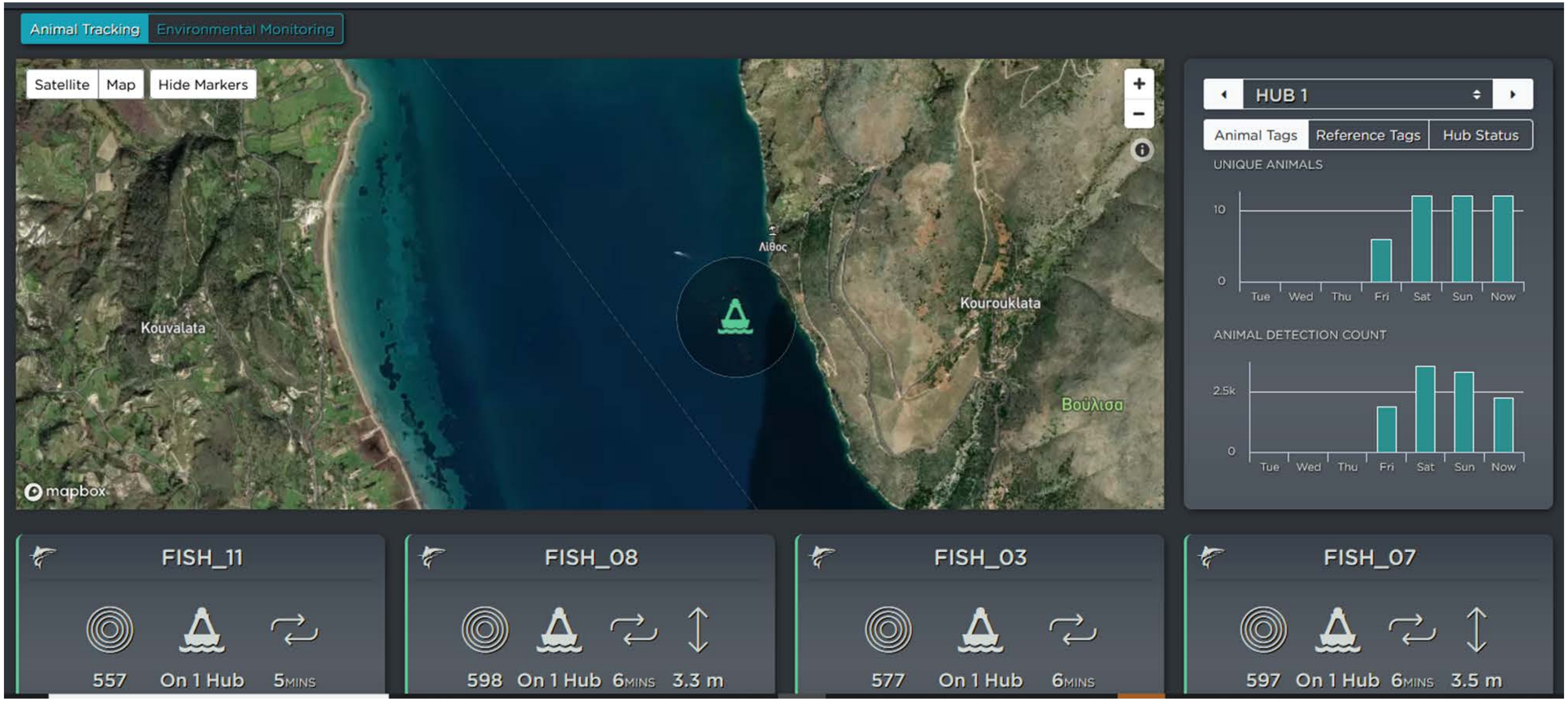
Environmental monitoring & fish tracking



Here and in the following two slides: some images of the life dashboard of the monitoring system

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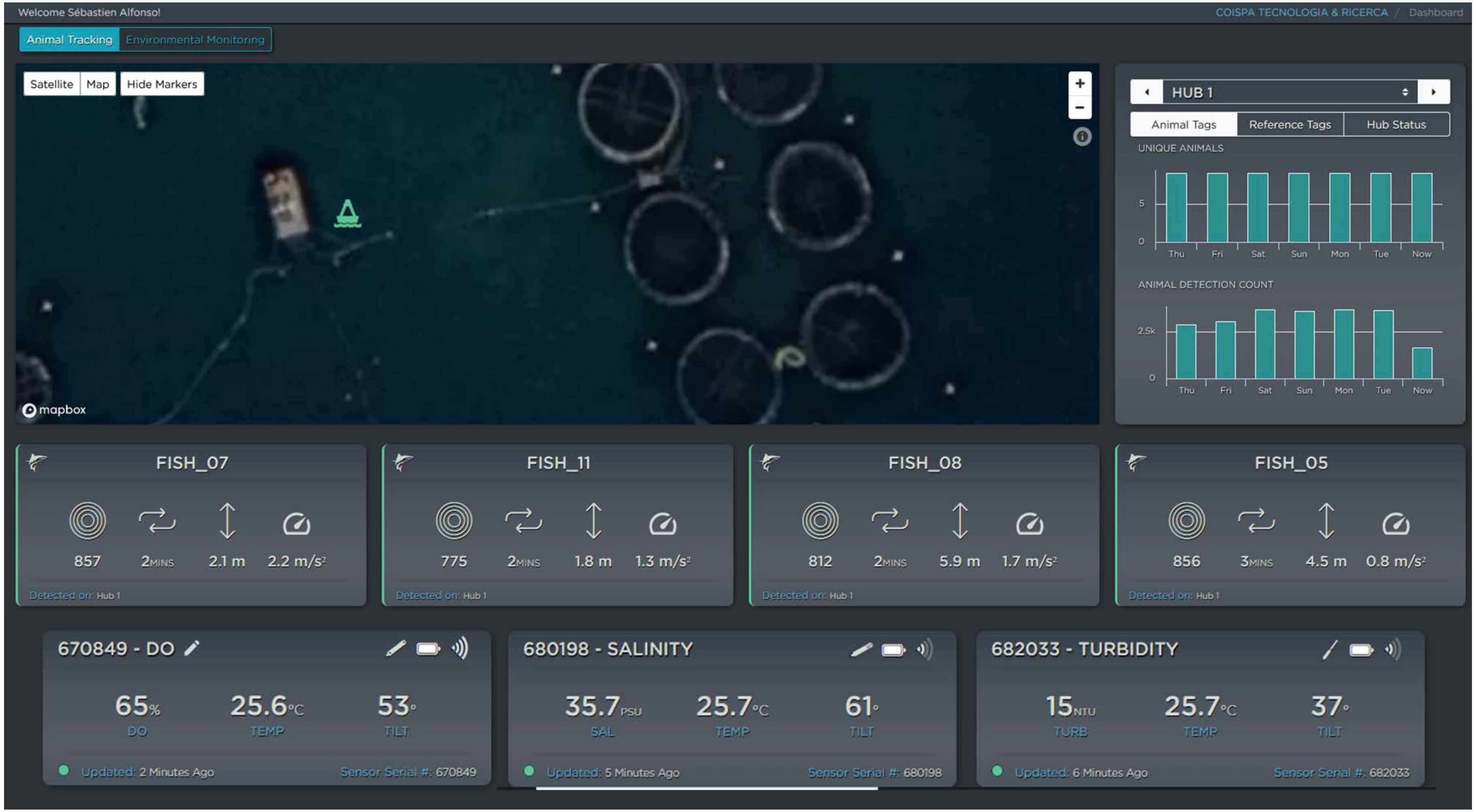
Environmental monitoring & fish tracking



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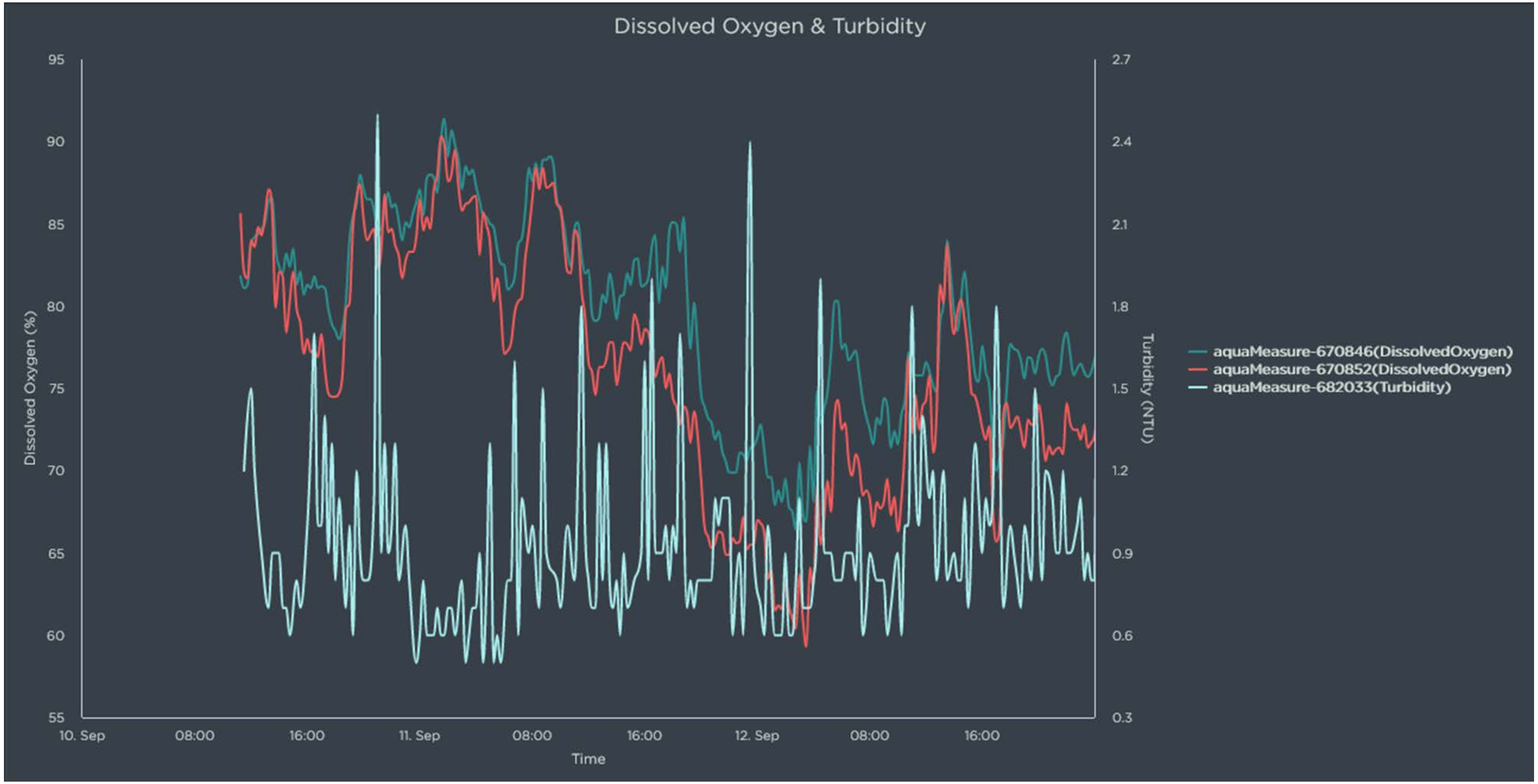
Environmental monitoring & fish tracking



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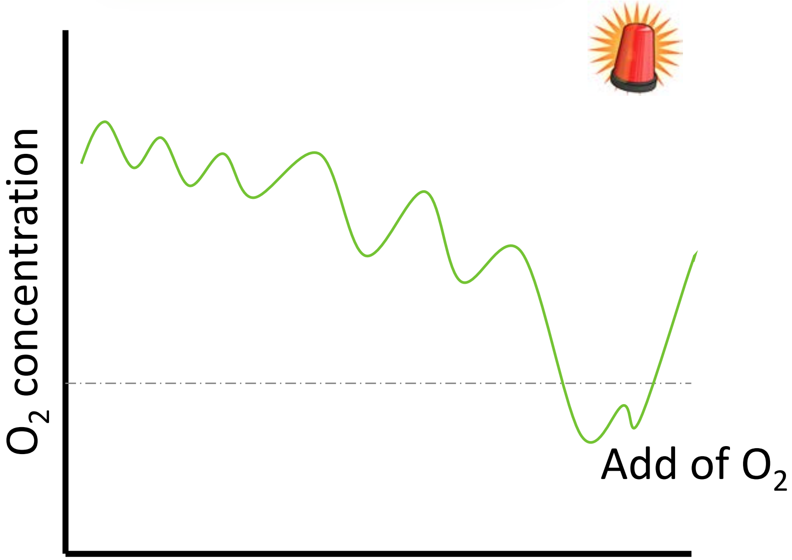
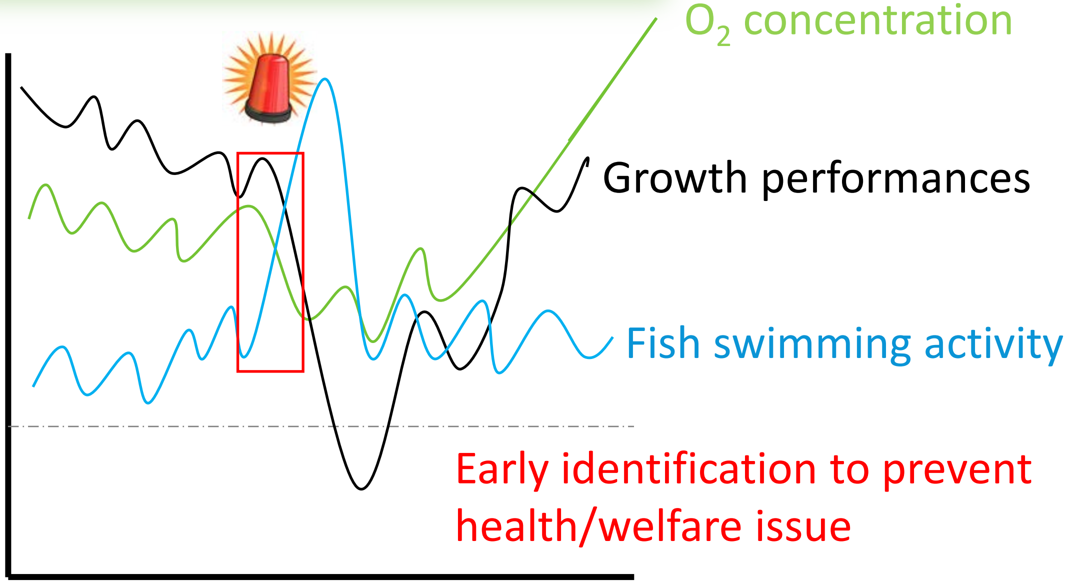
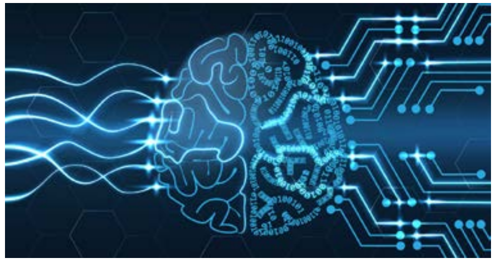
Future works

Where are we?



Where do we want to go?





Algorithmes / machine learning

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Click below to find more details on the wireless sensor networks and technologies applied in the FutureEUAqua project + a list of scientific literature, grey literature, web sites

Deliverable D5.1: State-of-the-art and future needs **LINK**

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SESSION III: Innovative fish feeds for health fish for a healthy human consumption

By Elena Mente - Aristotle University of Thessaloniki
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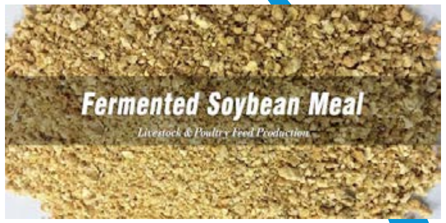
Nutrient sources from fishing activities

Fishmeal
Fish oil

Select
raw materials
FM and FO, krill meal, squid meal
Mineral and Vitamin premix
Novel ingredients

- *Pea protein*
- *Yeast*
- *Fermented soya*
- *Bacterial protein*
- *Yeast*
- *Microalgae*
- *Insects*
- *Tunicate meal*

Micro-macro
40 essential nutrients



Biotechnology

microalgae

bacterial protein

yeast

Nutrient sources from agricultural activites

Plant meals, land animal meals, PAPs,
by products meals and oils,
microbial feed ingredients

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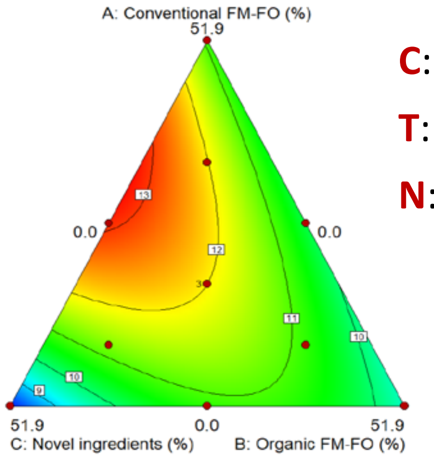
Sea bass novel diets

Lower values Novel ingredients

Higher values Novel ingredients

Low FIFO

•Bacterial protein
•Yeast meal
•Microalgae

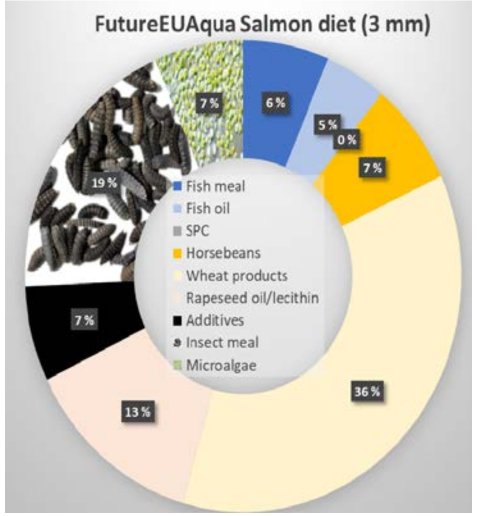


C: Conventional FM-FO

T: Trimmings FM-FO

N: Novel ingredients

Salmon novel diets



3 sets of chemical analyses, one for each group of materials used in the different fish trials:

1) Salmon & sea bream trials: Fish meal, tunicate meal, black solder fry meal, algal meals, biomasses and fish oil
2) Sea bass and sea bream trials: Conventional fish meal, fish meal made from trimmings, krill meal, bacterial protein, yeast protein, algal meal, squid meal, pea protein, rapeseed oil and fish oil, corn gluten, wheat gluten, soy bean meal.

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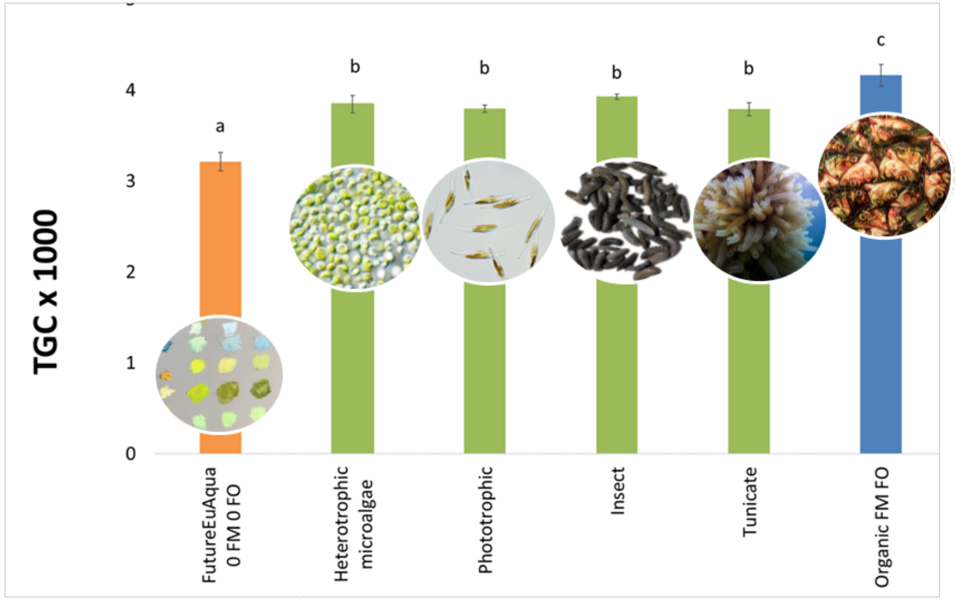
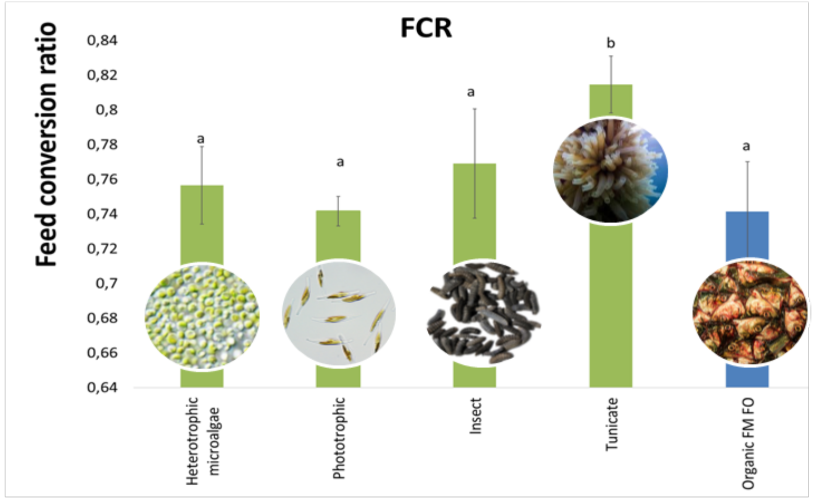
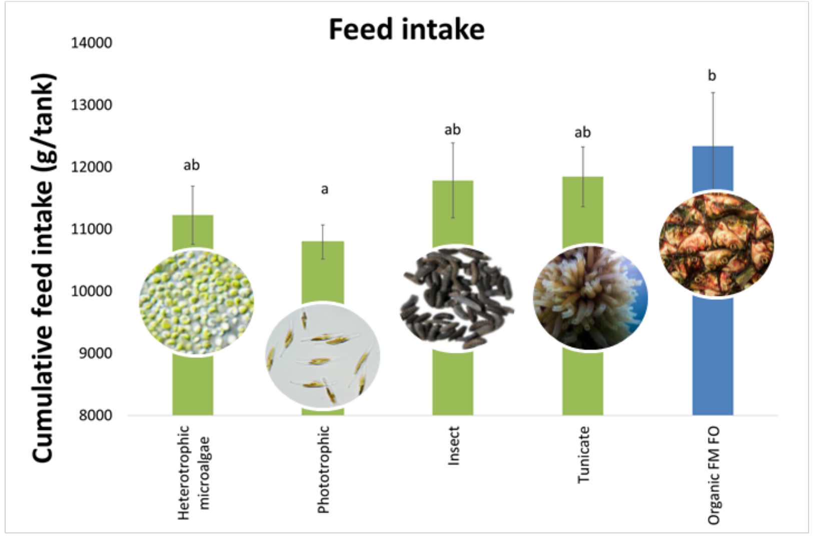
Fish performance

Kousoulaki, Sveen, Krasnov, Johansson, Norén, Richardson & Espmark







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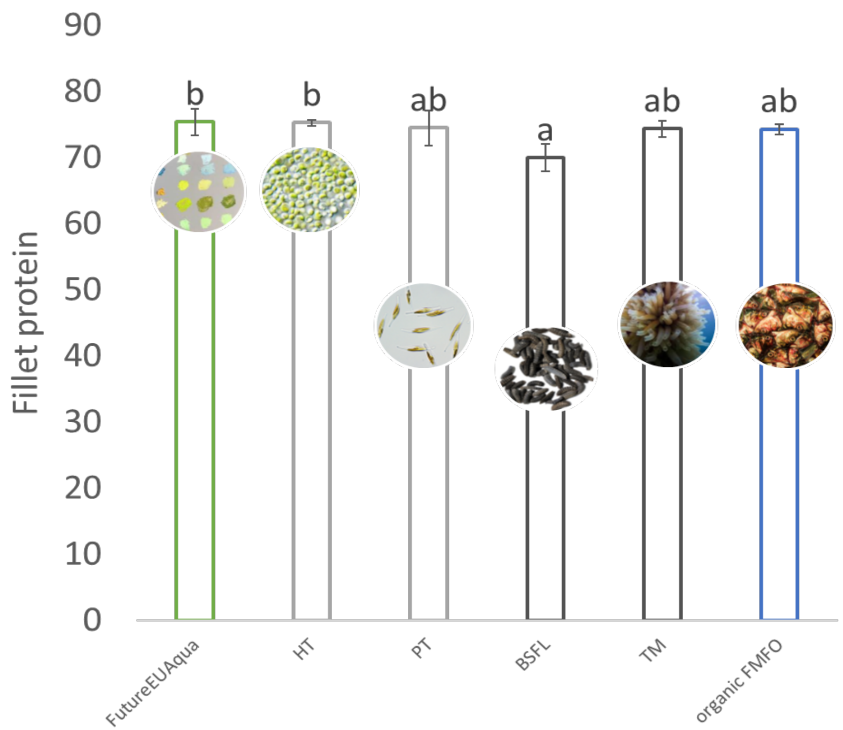
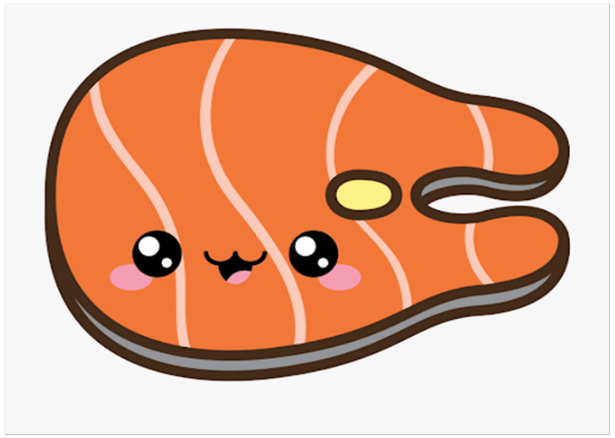
Product quality, fillet protein





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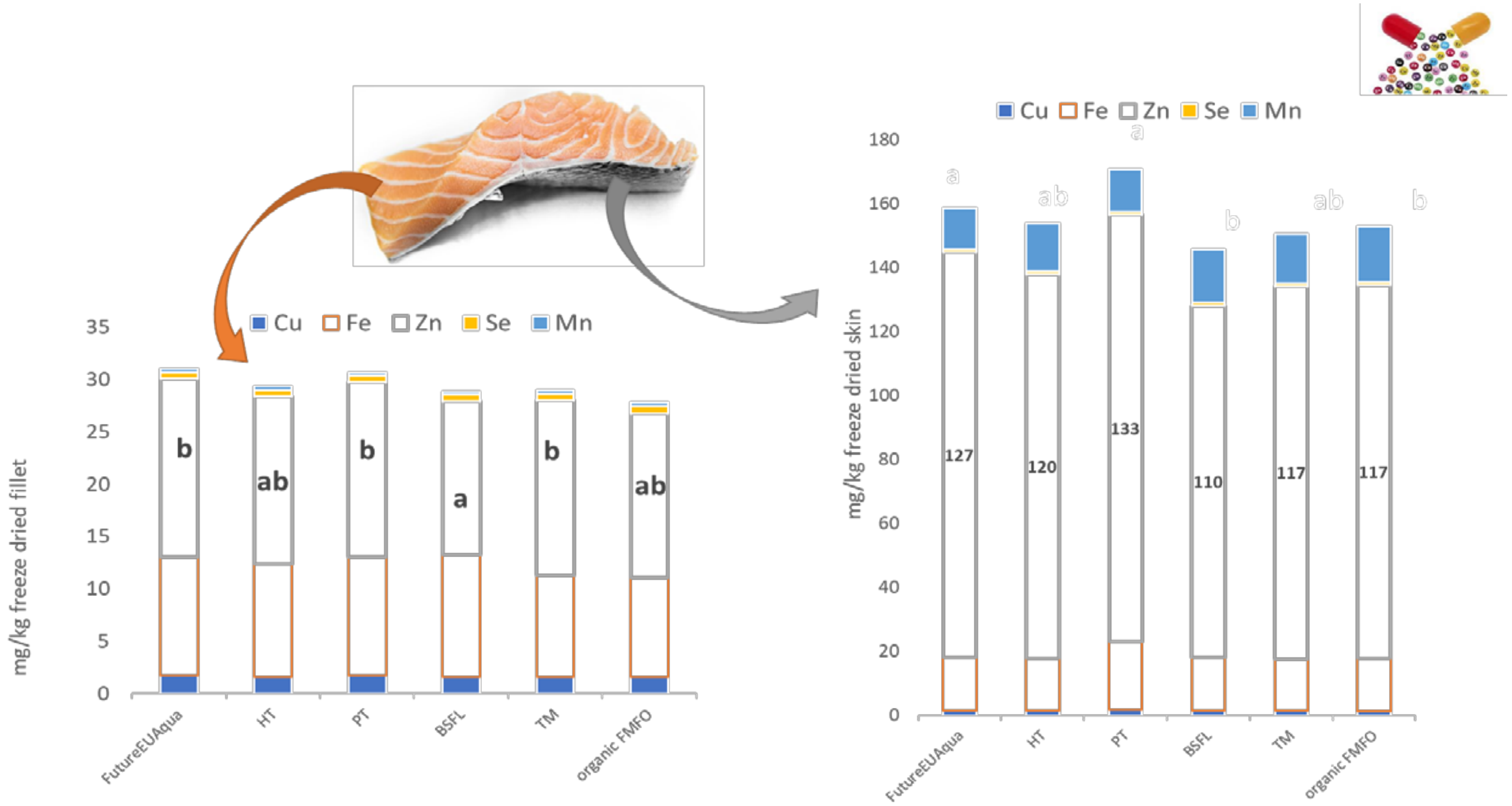
Health (skin and fillet mineralisation) and quality



INCREASED **FILLET** AND **SKIN ZN** LEVELS IN THE **PT MICROALGAE** GROUPS

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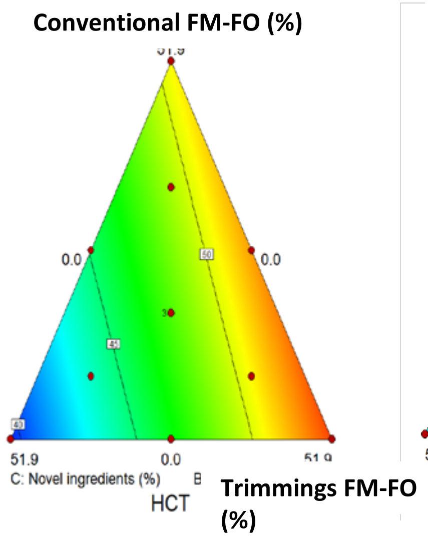
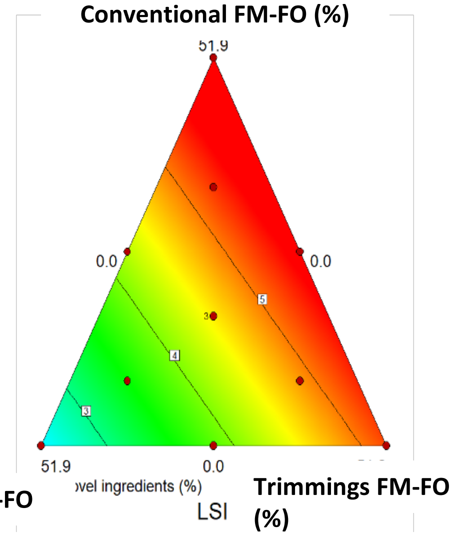


Haematocrit (HCT)



Liposomatic (LSI)

Best growth and FCR for **Conventional** and **Trimmings** mixture with **moderate** inclusion **of Novel ingredients**

Negative effects of exclusive inclusion of **Novel** ingredients possibly due to:

- Lower palatability (try palatability enhancers next)
- Lower digestibility

Ensure optimum mineral composition when use novel non marine source ingredients (Low haematocrit)

More fat was accumulated in both intestinal and liver tissues of **Conventional** and **Trimmings** fed groups. Possibly related to increased feed intake and final weight

The histopathological examination of the liver showed minimal (steatosis) lipid accumulation for Trimming mixture with moderate inclusion of Novel ingredients

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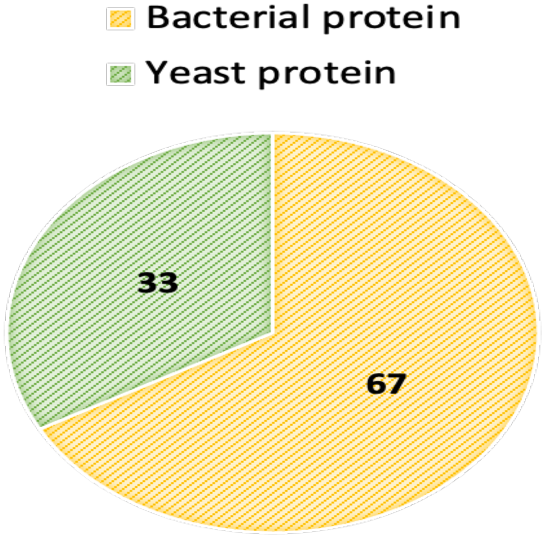
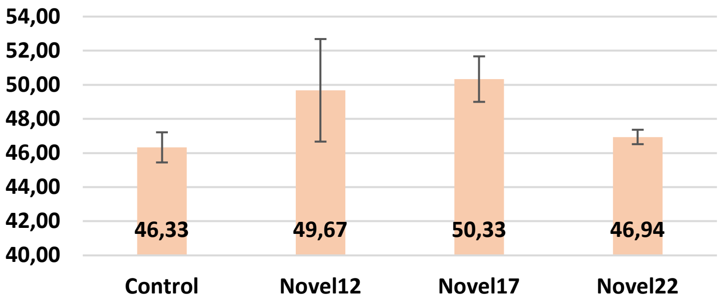
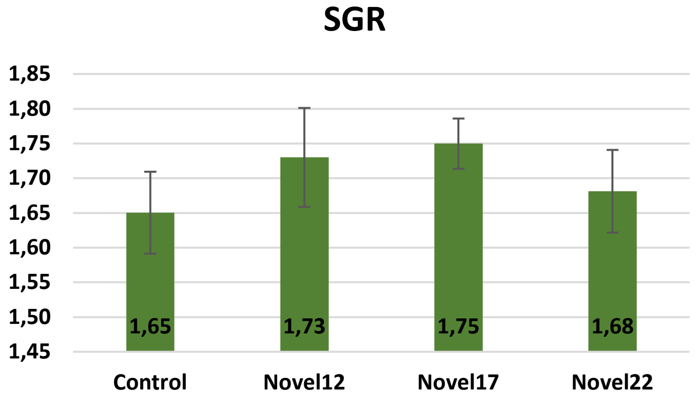
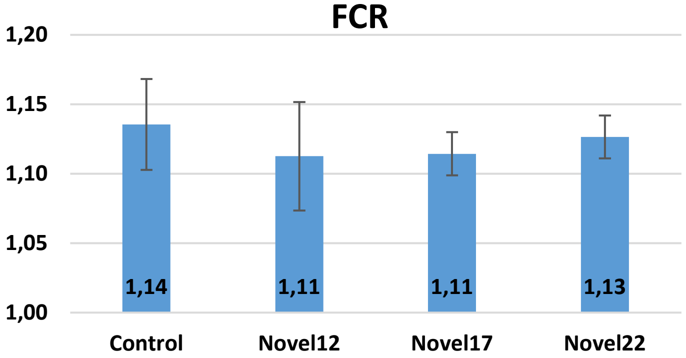
Novel ingredients mixture









- ✓ Trend observed for higher final weight of moderate inclusion of Novel ingredients
- ✓ Improved FCR at moderate inclusion of Novel ingredients

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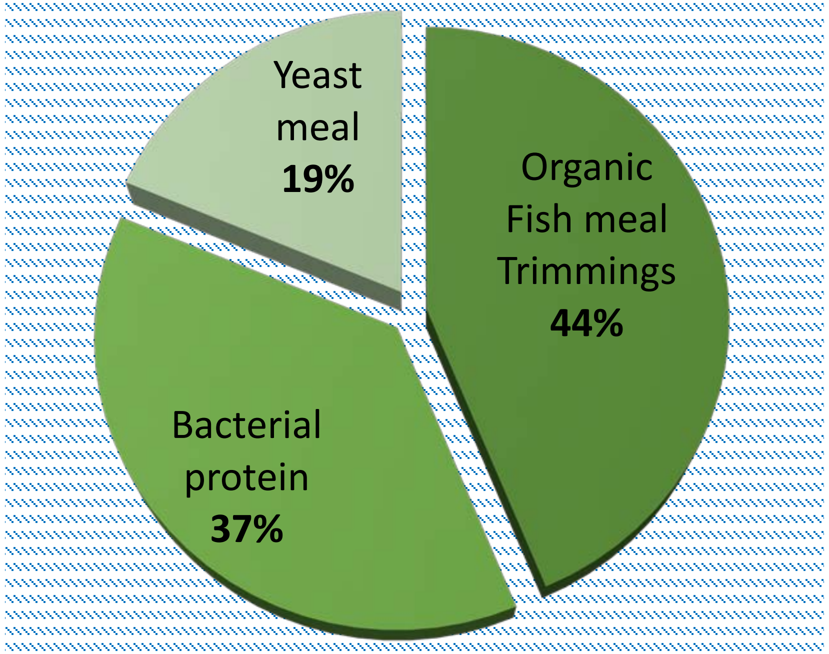
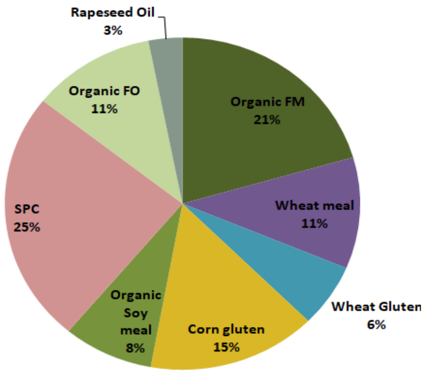
Diet 1 0% Low FiFo
Diet 2 20% Low FiFo
Diet 3 25% Low FiFo
Diet 4 30% Low FiFo

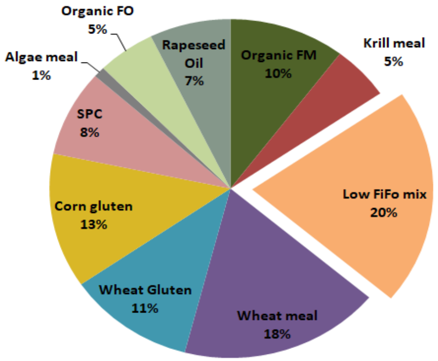
Low FiFo for organic diets



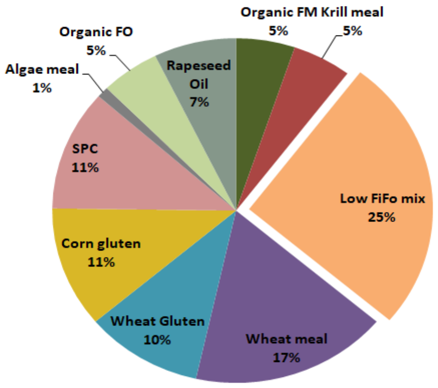
Higher growth performance for LFiFo25 diet compared to control diet



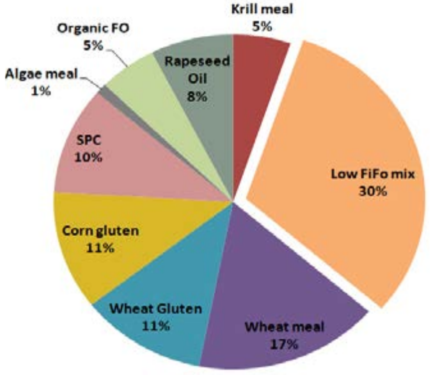
Diet 1



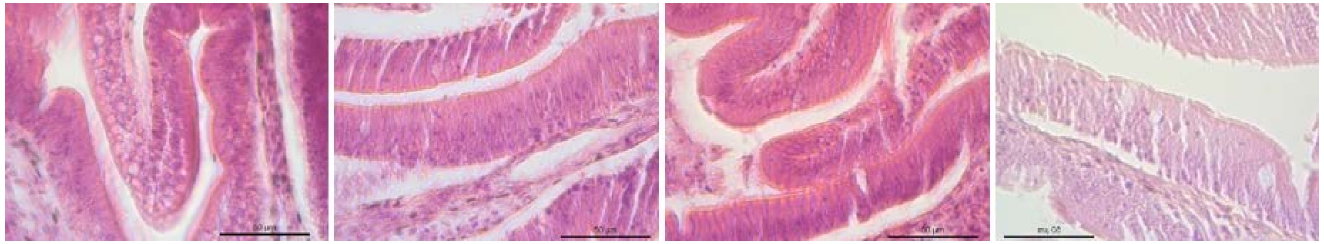
Diet 2



Diet 3



Diet 4



Anterior gut, liver appears to have normal structure in all dietary groups with normal distribution of goblet cells.

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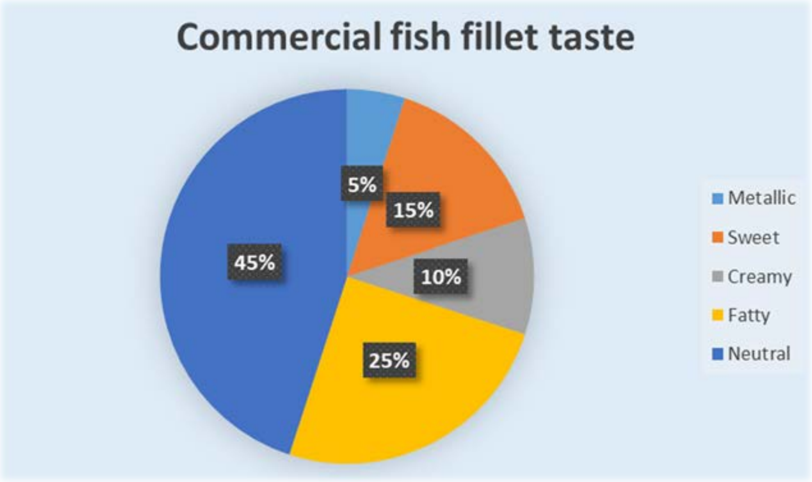
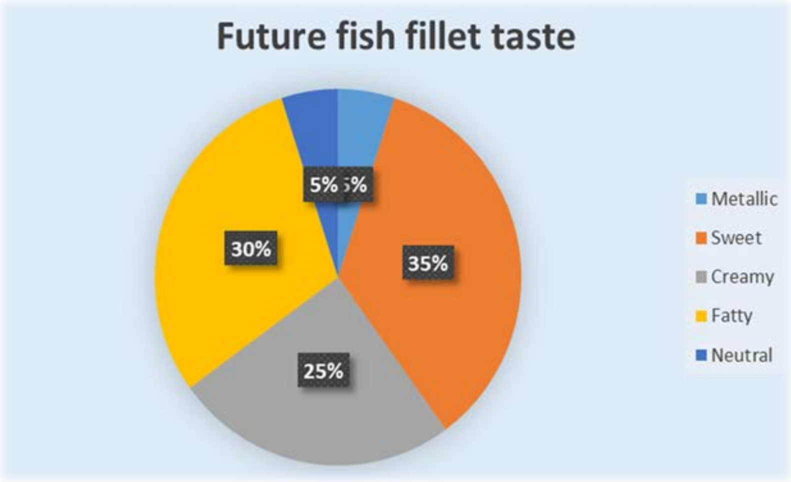
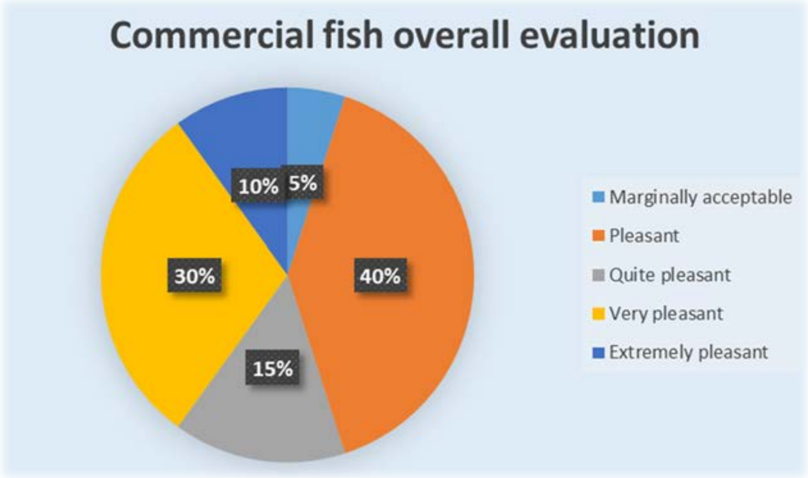
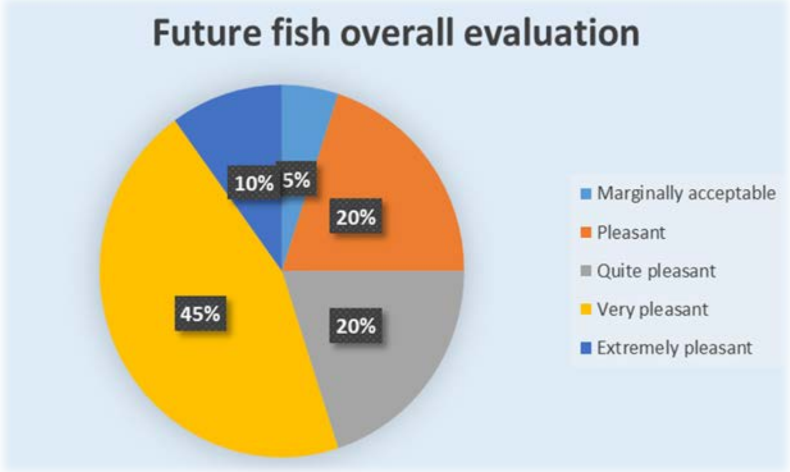
Commercial diet

FutureEUAqua diet









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Fish gut microbiota and nutrition

Gut microbial diversity could be influenced
by nutrition or environmental factors
but few studies on fish and crustaceans are available that experimentally confirm this.

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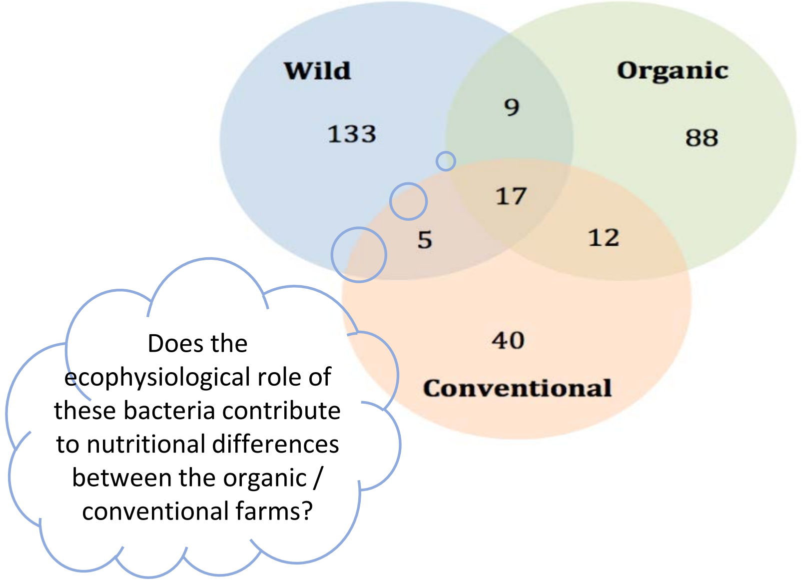
• Do gut bacterial communities exhibit temporal shifts/diversity mostly relating to temporal variations in food supply of nutrients?

• Which are the gut bacterial communities that could serve as providers of essential nutrients to fish?



Diet is a major factor driving the composition and metabolism of the gut microbiota while gut microbiota is actively involved in nutrient assimilation and immunity of the host organism.

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SESSION IV: Metabolic traits of free-swimming fish in aquaculture

By Giuseppe Lembo and Sebastien Alfonso – COISPA Tecnologia & Ricerca
Email: lembo@coispa.it

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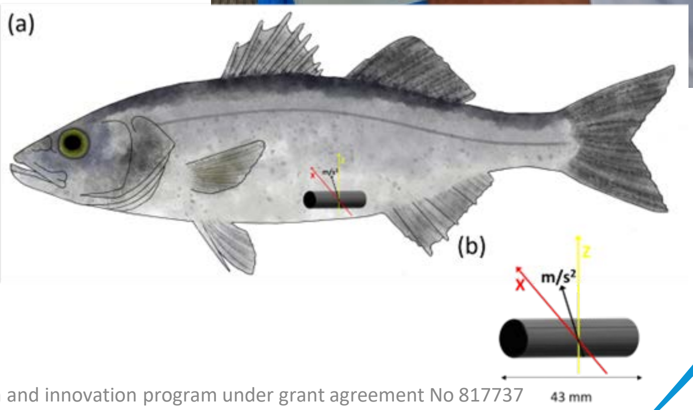
Metabolic traits of free-swimming fish in aquaculture

- Electronic sensors are significantly improving the possibility to monitor fish condition and are emerging as key sources of information for improving aquaculture management practices (Føre et al., 2018; Halachmi et al., 2019; Brijs et al., 2021).
- Enhanced biological (e.g. behaviour, activity, energetic, feeding physiology) sensor data, collected by on-board electronic tags, will provide accurate fine-scale measurements of fish health and welfare during the aquaculture production cycle.



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Metabolic traits of free-swimming fish in aquaculture

To this purpose, we firstly need to establish a baseline of information, for each of the target species, regarding: i) muscular activity patterns linked to oxygen consumption; ii) mass specific standard metabolic rate (SMR); iii) maximum metabolic rate (MMR). Then, the calibration of critical swimming speed (U_{crit}), electromyograms (EMG), oxygen consumption (MO_2) with accelerometer sensors gives the possibility to correlate each single swimming level to a metabolic state or to an activity index expressed as the EMG level. In particular, EMGs measure red (aerobic metabolism) and white (anaerobic metabolism) muscle activity. The EMG level at the U_{crit} speed represents the threshold limit of the aerobic muscular activity. In this way, the activity based energetic expenditure can be assessed and, consequently, the fish physiological status, as well as the relative cost of living for fish in their environment.

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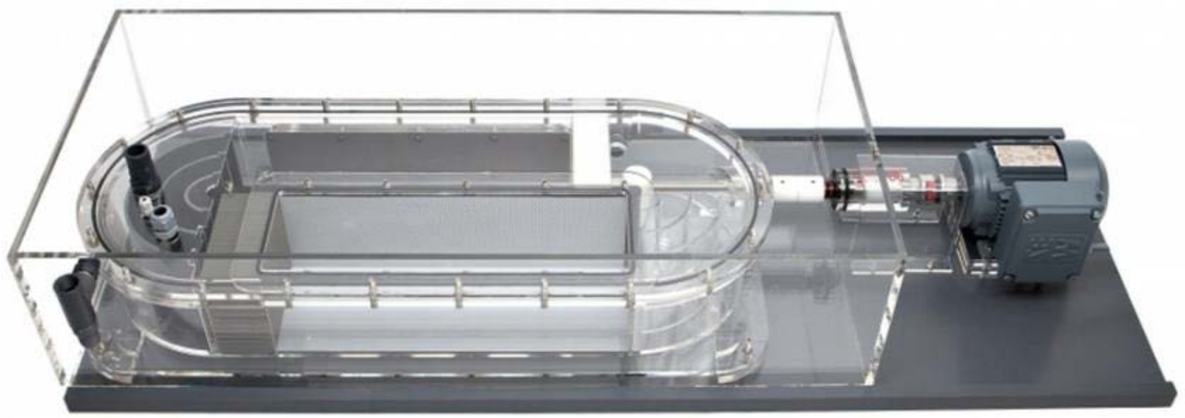
Swimming performances and energetic expenditure

- The oxygen consumption rate (MO_2) can be measured during exhaustive swimming trials (U_{crit}), carried out in swimming chambers to estimate the energetic expenditure of the fish linked to the different swimming velocities.
- After the acclimatation of the fish in the swimming chamber, the swimming tests are conducted by imposing a swimming speed ramp (0.1 m s^{-1}) at constant time intervals (10 min) until the fish reaches a state of fatigue (Carbonara et al., 2010).



(https://www.loligosystems.com/swim-tunnel-respirometer-3)

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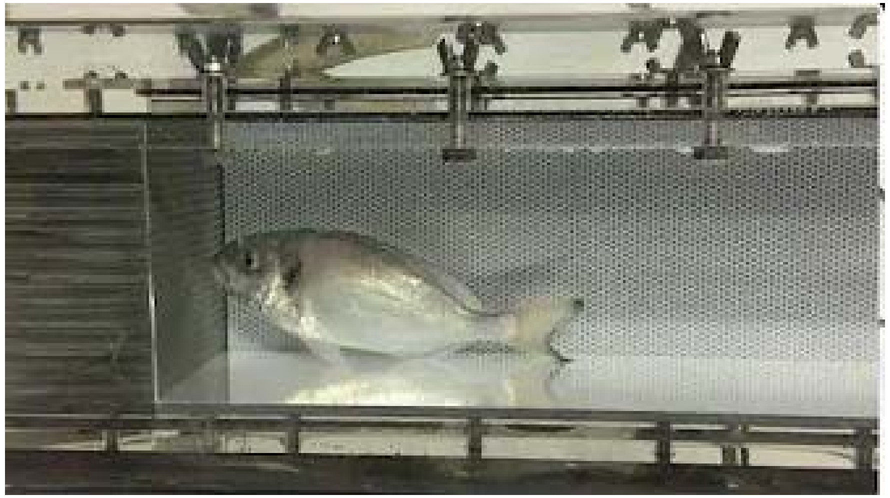
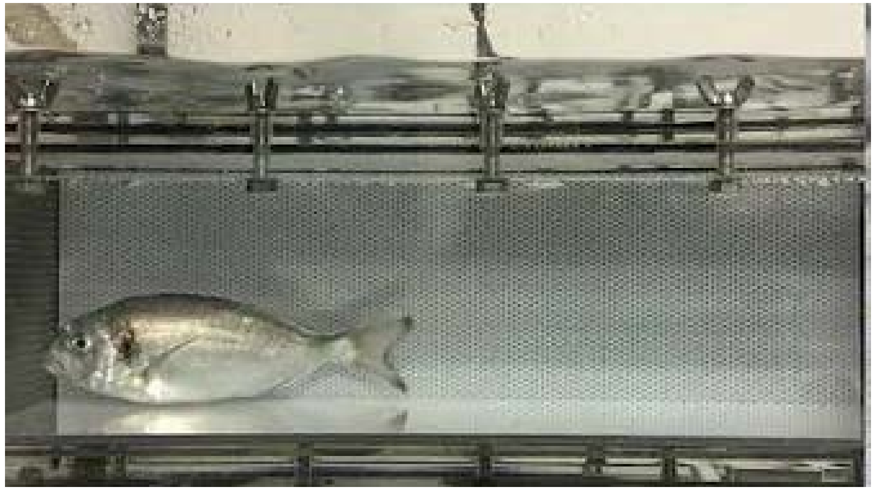
Swimming performances and energetic expenditure

Each water speed step is constituted of 3 steps: a 5-min step of “flushing”, 2-min step of “waiting” and 3-min step of “MO_2 measurement”.
During the MO_2 measurement step, the oxygen concentration of the swim tunnel water is recorded every second.



Slow speed swimming



Fast speed swimming

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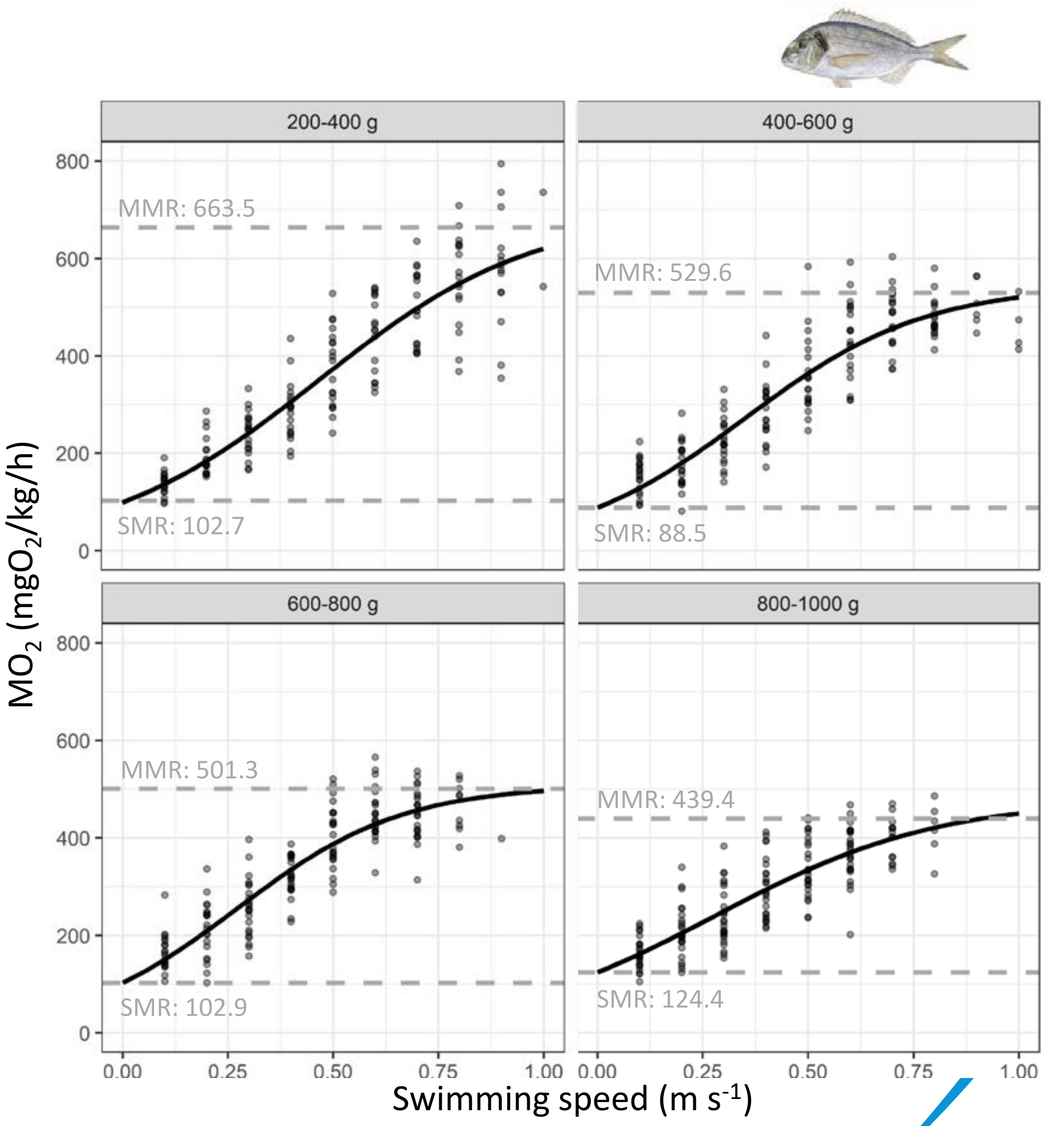
Swimming performances and energetic expenditure

The bioenergetics of the target species (muscular activity patterns) can be modelled, based on fish mass and swimming speed, to assess: i) the mass-specific standard metabolic rate (SMR), ii) the active metabolic rate (AMR) and iii) the scope for activity (SFA). The numerical difference between AMR and SMR indicates the energetic expenditure available to support all locomotor and physiological activities (SFA).



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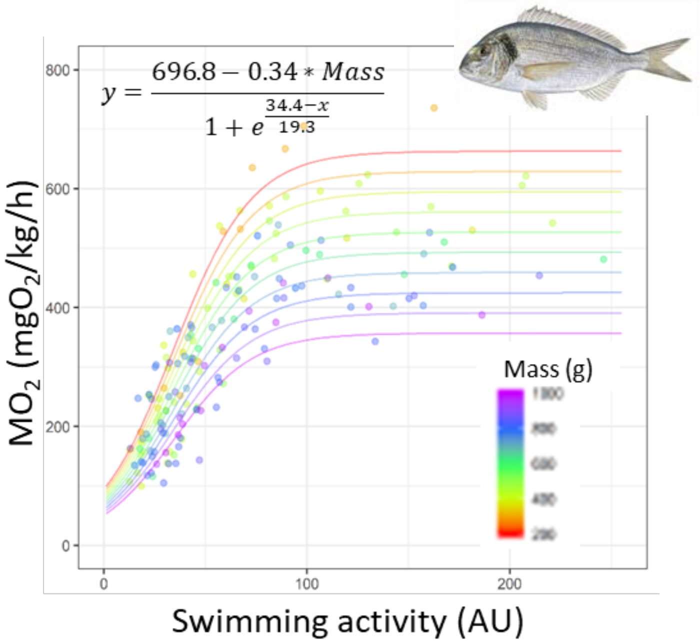
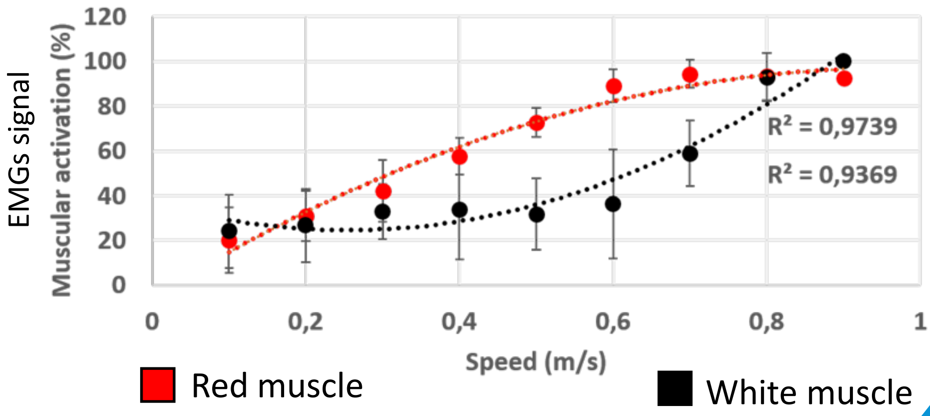
Swimming performances and energetic expenditure



- MO_2 can be further calibrated, during the U_{crit} tests carried out in the swimming chamber, with the signals transmitted by the tailbeat accelerometer tags implanted to the fish (Alfonso et al., 2021).
- MO_2 can be also calibrated with the EMGs signal received via two pairs of wire electrodes surgically implanted in both the red and white muscle (Zupa et al., 2015).
- In this way, the activity based energetic expenditure can be assessed and, consequently, the fish physiological status too, as well as the relative cost of living for fish in rearing conditions.



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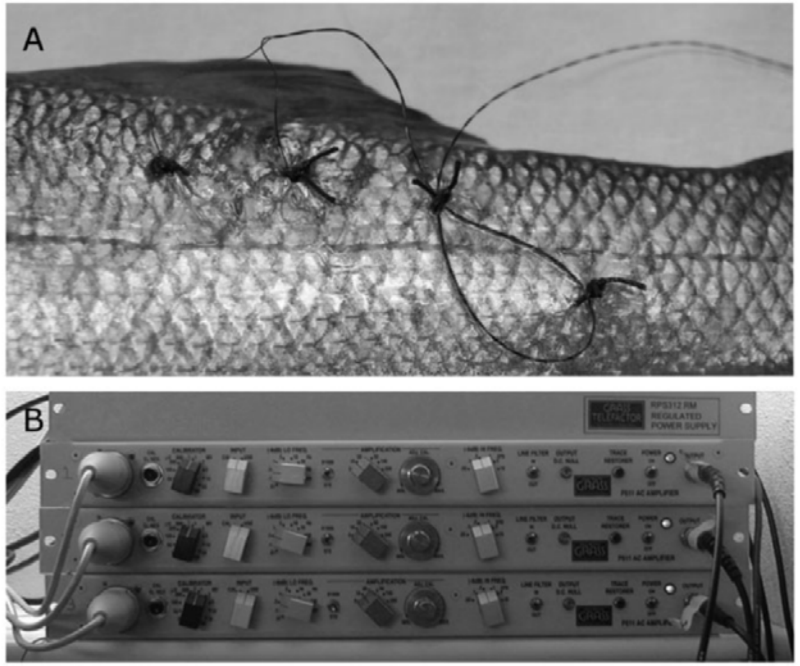
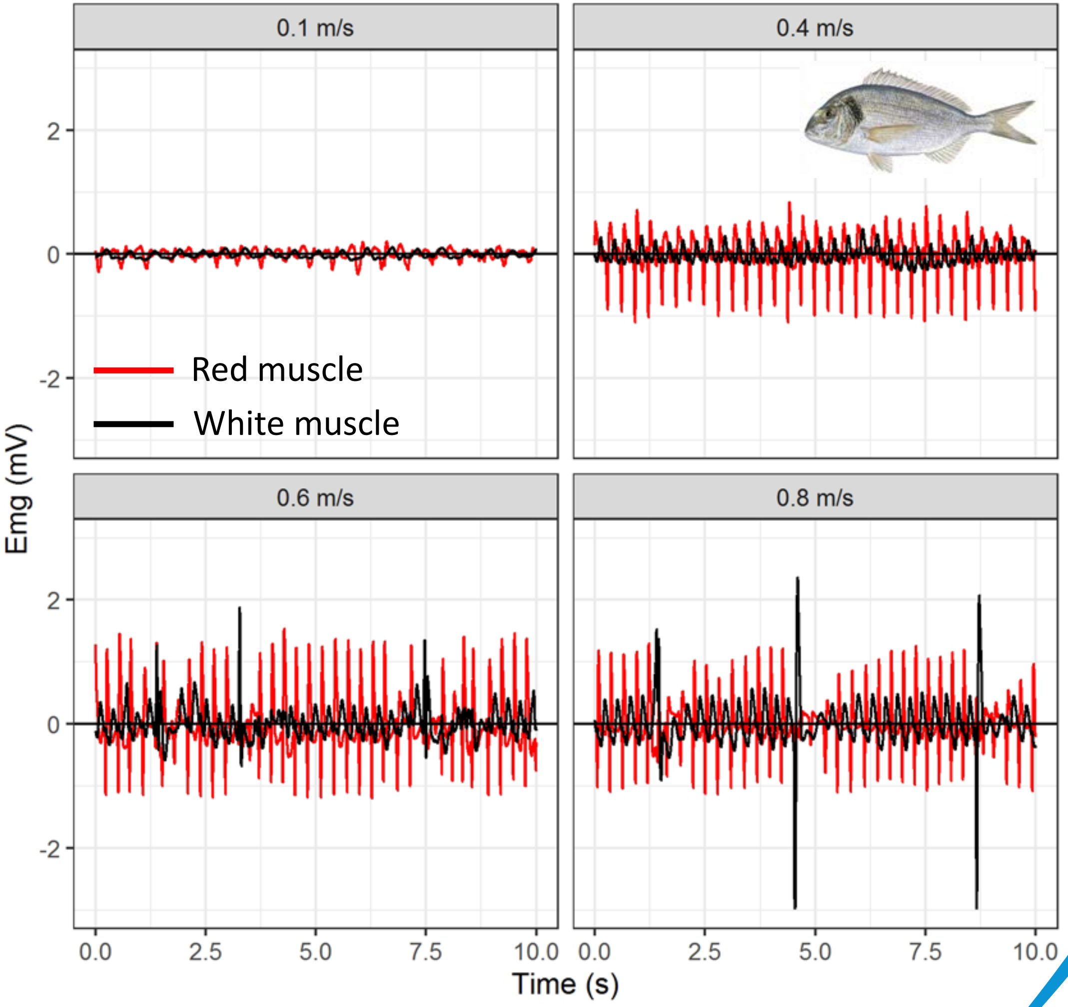
Swimming performances and energetic expenditure





Red muscle

Aerobic activity

White muscle

Anaerobic activity

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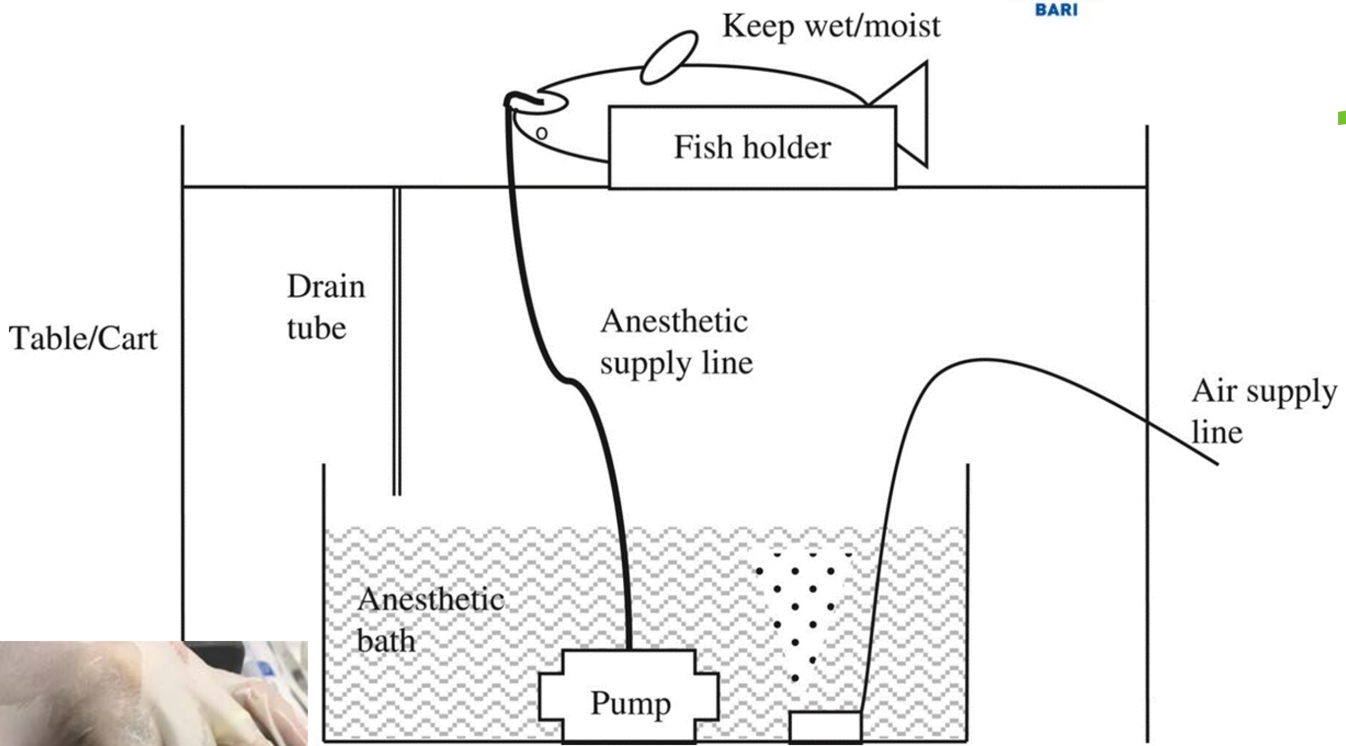
Tag implanting



Fish are initially anaesthetized using a hydroalcoholic clove oil solution and gills are continuously irrigated during the surgery using a maintenance level of anesthetic.

Then the tag is inserted into the body cavity, through a 1.5 cm incision, which is closed using three independent surgical sutures.

Lembo et al., 2007

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Some results of the experiments carried out at *Avramar* aquaculture farm and *Kefalonia Fishery* aquaculture farm

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Experiment protocol

Feeding trial: commercial vs. Innovative diet

SENSOR DATA

T_0 July 2020

Blood sampling
Organ sampling

T_1 *Dec. 2020*

Blood sampling
Organ sampling
Implantation of tag

T_2 *Summer 2021*

Blood sampling
Organ sampling

	T0	T1	T2
Date	14-15/07/2020	24-25/04/2021	06-07/07/2021
Sample size	10	18 per condition	20 per condition
Mass (g)	29.71 ± 4.24	310.44 ± 128.75	379.94 ± 137.70
TL (mm)	137.34 ± 6.15	290.97 ± 33.21	316.58 ± 38.48

AVRAMAR Better Fish, Better Lives

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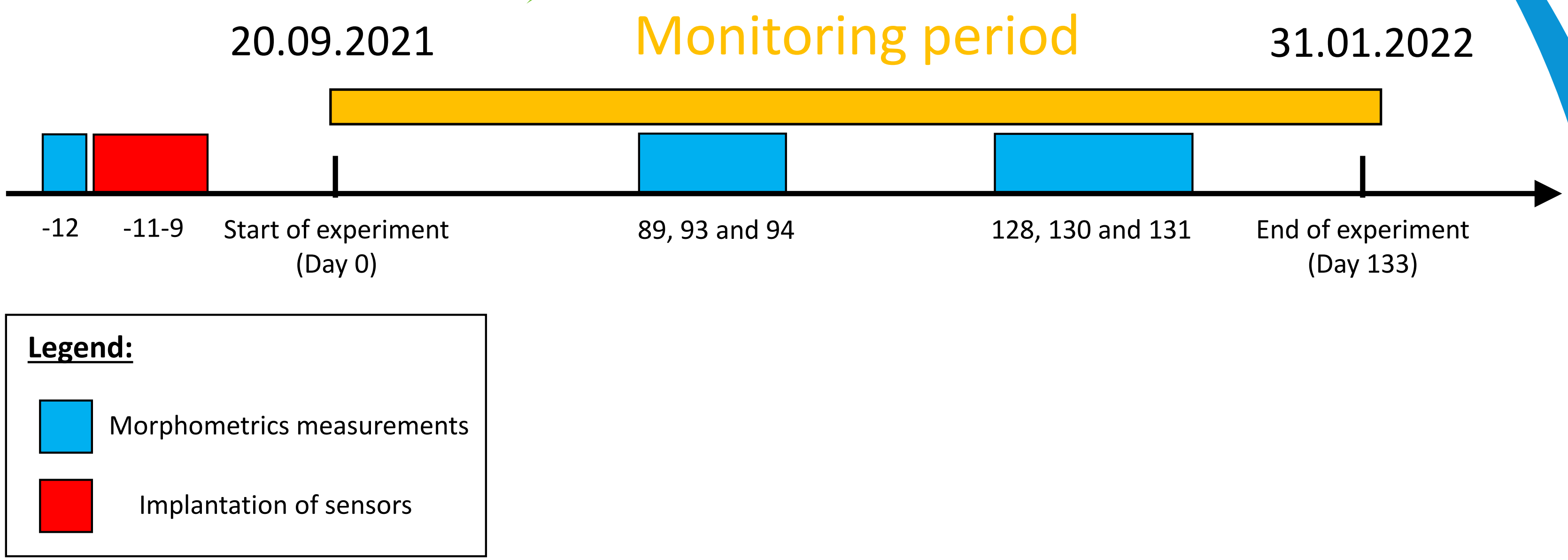
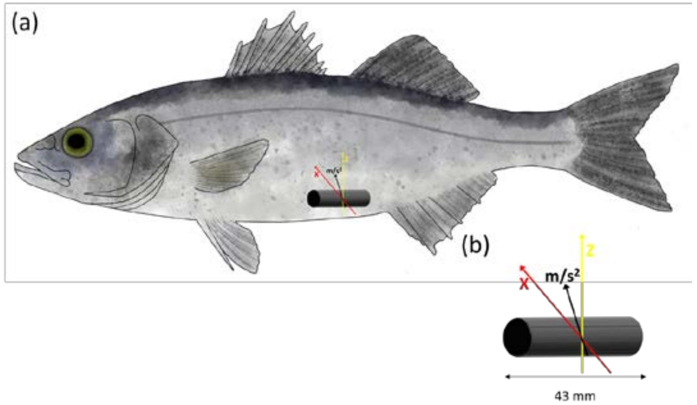
Experiment protocol





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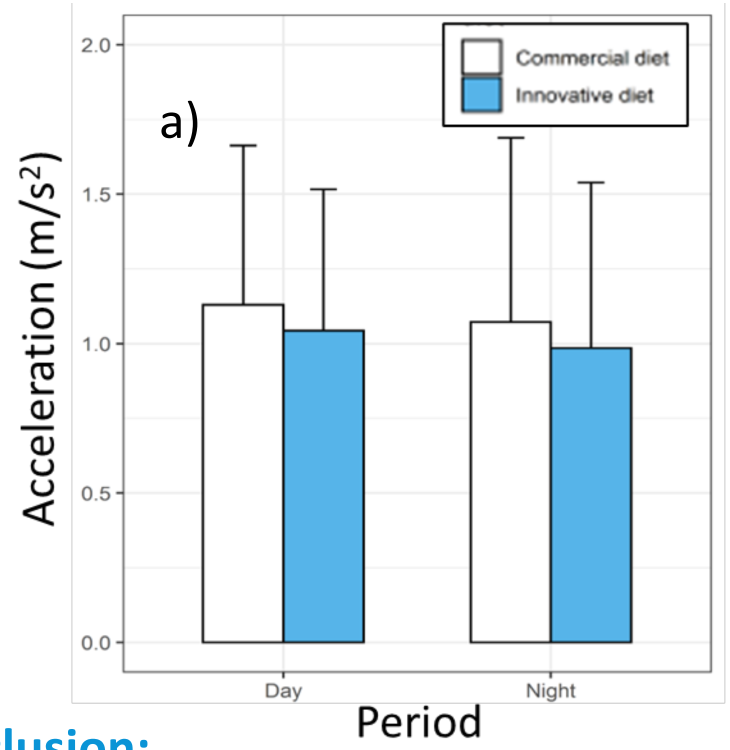
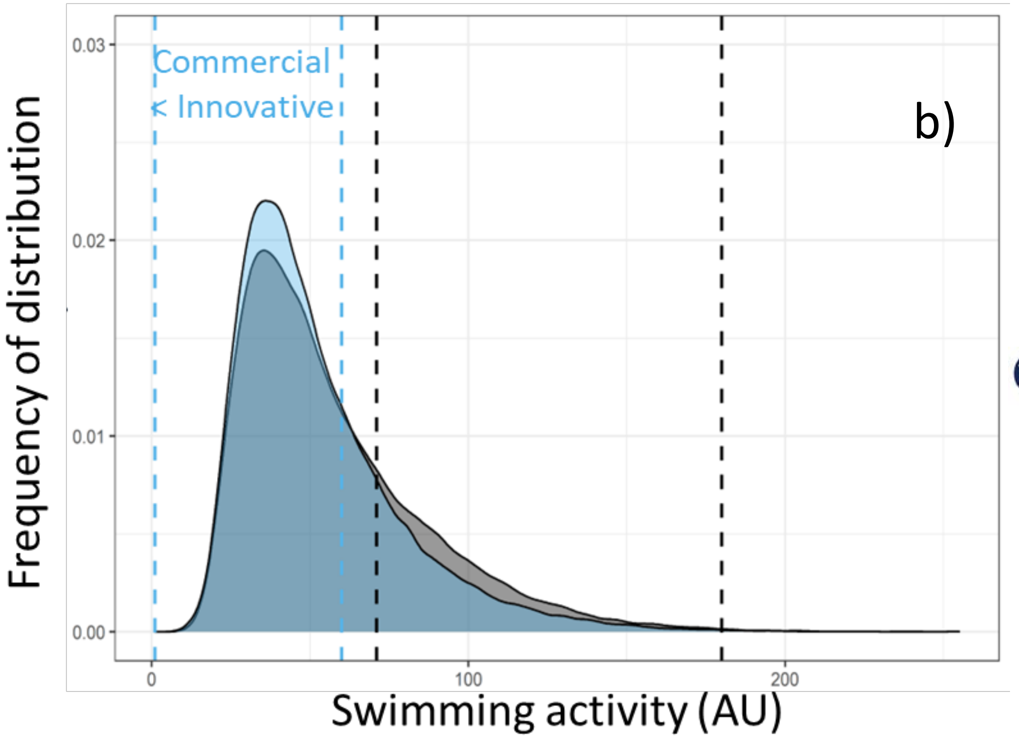
Acceleration recorded by sensors as a proxy of energy expenditure





AVRAMAR Better Fish, Better Lives

Conclusion:

a) Sea bass fed innovative diet tends to display lower acceleration over the experimental duration (p=0,057).

b) At high levels of swimming activity fish fed commercial diet shows higher acceleration (that means higher anaerobic expenditure).

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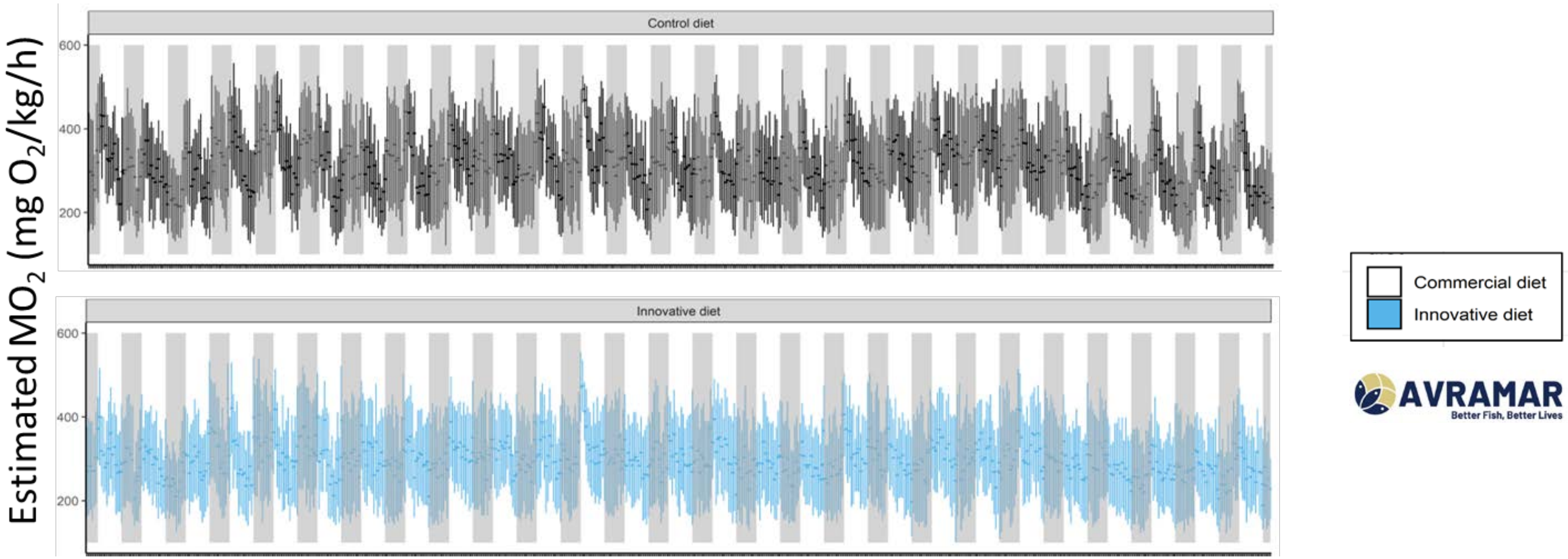
Acceleration recorded by sensors as a proxy of energy expenditure



AVRAMAR Better Fish, Better Lives

Conclusion:

- Sea bass fed on innovative diet tends to display lower oxygen consumption over the experimental duration, while sea bass fed the commercial diet tends to display lower availability of energetic reserves.

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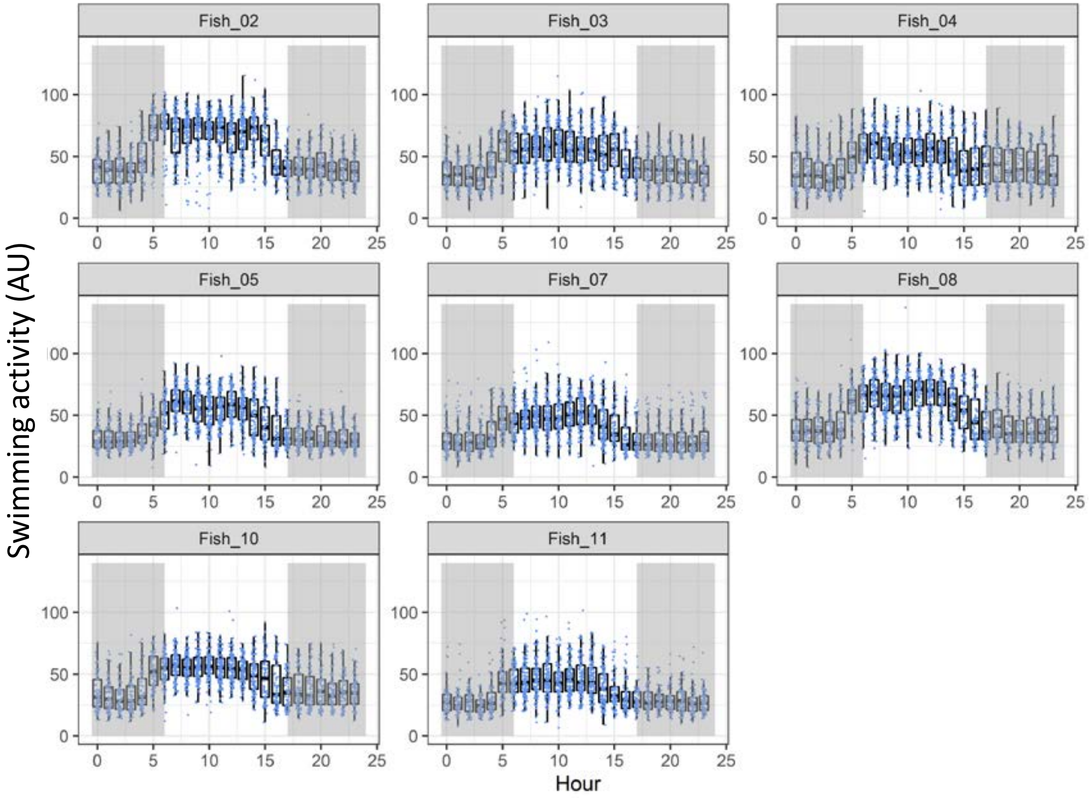
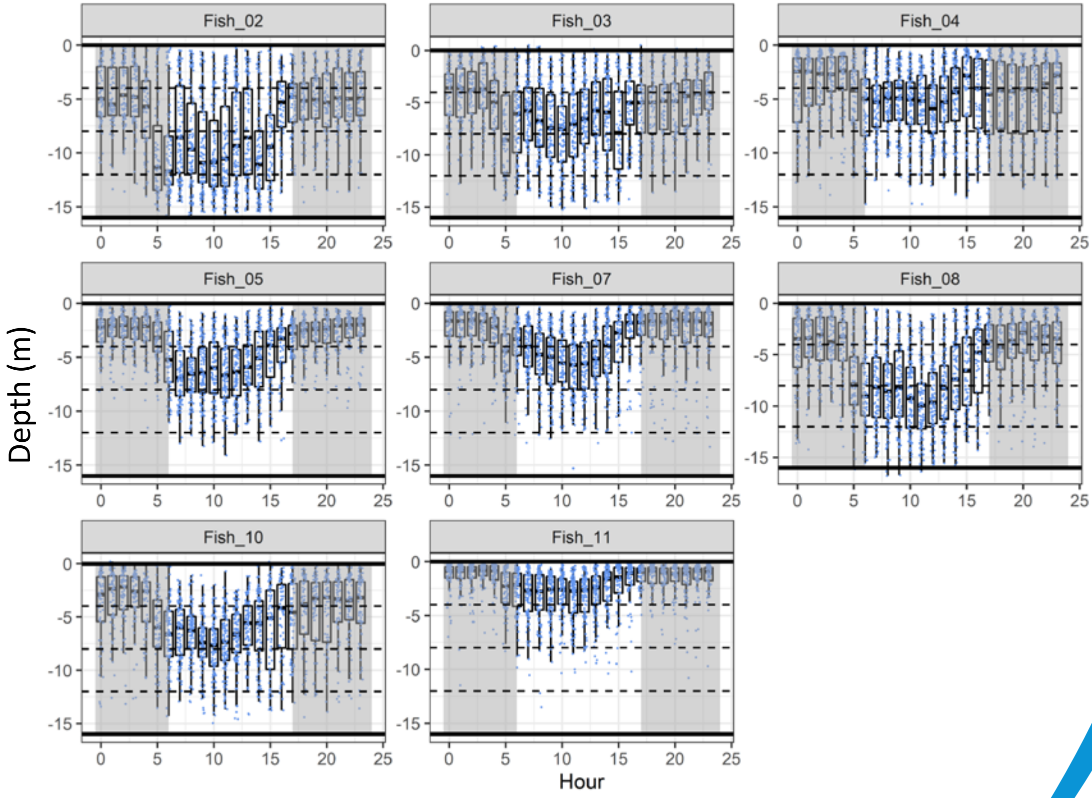
Daily swimming activity pattern





KEFALONIA fisheries

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Click below to find more details on how the measurements of fish metabolic rates can improve aquaculture management practices, as well as welfare & performance in farmed fish

Deliverable D5.2: Calibration of physiological sensors technologies **LINK**

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Glossary

- **Nutrition**: the provision of all indispensable nutrients in adequate amounts to insure proper growth and maintenance of body functions; involves various chemical reactions and physiological transformations which convert feed into body tissues and activities; involves ingestion, digestion and absorption of various nutrients; transport into cells; removal of unusable elements and waste products of metabolism.
- **Nutrient:** nutrients are chemical compounds in feed that are used by the animal organism to meet its physiological function, grow and maintain health.
- **Essential nutrient:** provided in the diet in order to insure adequate growth and maintenance
- **Nutrient categories**: macro and micro
  -macronutrients: protein, lipid, carbohydrate, etc.
  -micronutrients: trace metals, vitamins
- **Nutrient requirement:** The amount of each specific nutrient that fish needs to sustain all its physiological functions for growth, reproduction while maintain a healthy life.
  proteins: g/kg vitamins: µg/kg

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Glossary

- **Critical swimming speed (U_{crit}):** the maximum sustained swimming velocity that various fish species are able to sustain for prolonged periods.
- **Electromyograms (EMGs):** measure the electrical activity produced by muscles. The red (aerobic metabolism) and white (anaerobic metabolism) muscle activity.
- **Red muscles:** are aerobic muscles mainly used when fish swims within low swimming speed.
- **White muscles:** are mostly anaerobic mainly used in prolonged swimming at high swim speeds, what eventually leads to fatigue.
- **Aerobic Scope – AS:** also called Scope For Activity - SFA, is the numerical difference between MMR and SMR indicates the energetic expenditure available to support both locomotive and physiological activities.

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Enjoy the module!

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